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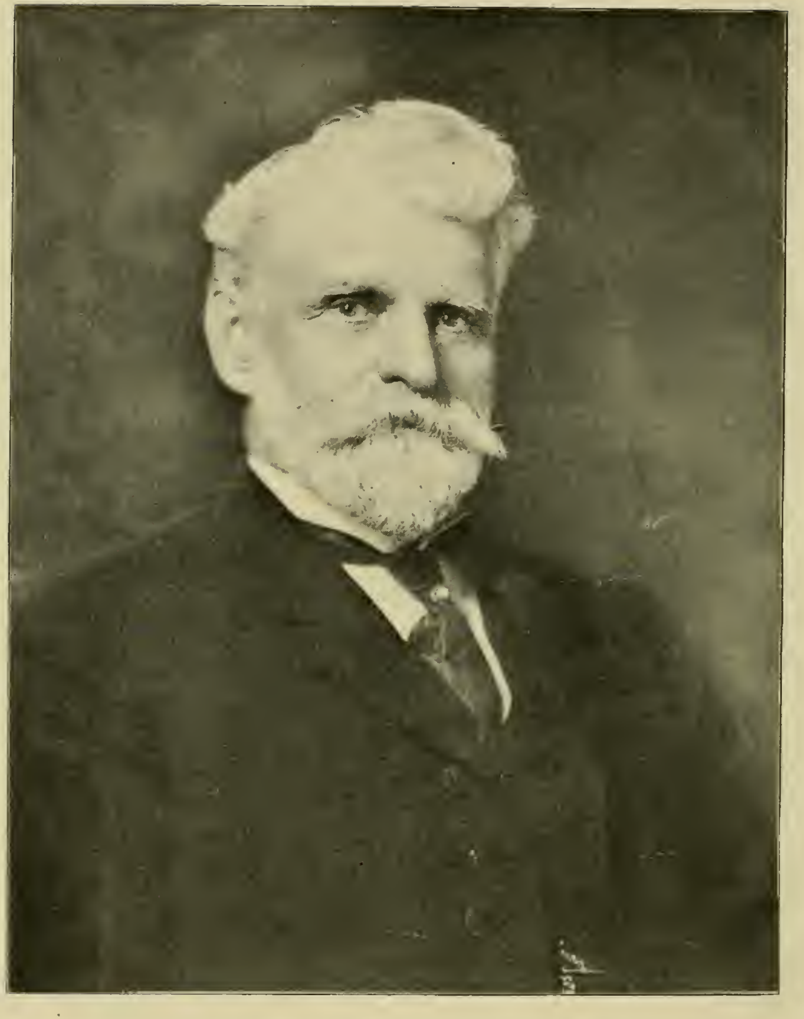

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BULLETIN

OF THE

SCIENTIFIC LABORATORIES

OF

DENISON UNIVERSITY

EDITED BY
FRANK CARNEY

VOLUME XVI
1910-1911

GRANVILLE, OHIO

CONTENTS OF VOLUME XVI

June, 1910

1. The Metamorphism of Glacial Deposits. By F. Carney.... 1
2. Preliminary Notes on Cincinnatian and Lexington Fossils of Ohio, Indiana, Kentucky, and Tennessee. By Aug. F. Foerste.... 17
3. The Abandoned Shorelines of the Oberlin Quadrangle, Ohio. By F. Carney.... 101

December, 1910

4. Standardization of Well Water in the Vicinity of Granville, Ohio. By Lily Bell Sefton.... 119

Chapters on the Geography of Ohio. By F. Carney

5. Transportation.... 125
6. Economic Mineral Products.... 137
7. Glaciation in Ohio.... 183

April, 1911

8. The Abandoned Shorelines of the Vermilion Quadrangle, Ohio. By F. Carney.... 233
9. Thermo-electric Couples. By A. W. Davison.... 245
10. The Mercer Limestone and its Associated Rocks in the Newark-Zanesville region. By Clara Gould Mark.... 267
11. A Study of the Supposed Hybrid of the Black and Shingle Oaks. By Earl H. Foote.... 315
12. A Case of Pre-Glacial Stream Diversion near St. Louisville, Ohio. By Howard Clark.... 339

July, 1911

13. The Swasey Observatory, Denison University. By Herbert G. Wilson.... 347
14. The Contribution of Astronomy to General Culture. By Edwin B. Frost.... 353

Chapters on the Geography of Ohio. By F. Carney

15. The Geologic Development of Ohio.... 365
16. The Relief Features of Ohio.... 380
17. Geographic Conditions in the Early History of the Ohio Country.... 403

SUBJECT AND AUTHOR INDEX

Volume XVI

Page

- Abrasives in Ohio, natural and artificial 157
- **Adams**, On effect of pressure on marble 11
- Agencies of alteration of glacial sediments 5
- Analysis for establishing standard of purity of water in wells 119
- Appalachian mountain-making movement 370–388
- Appalachian route to Ohio 405
- Ashtabula river 393
- Astronomy, history of, ... 353
- Black river 394
- Blast furnaces in Ohio, statistics of 140
- Building stones of Ohio 143
- Calymene abbreviata, sp. nov 83
- Calymene callicephala, Green 83
- Calymene meeki, nom. nov 84
- Calymene meeki-retrorsa 85
- Calymene senaria, Conrad 82
- Calymene platycephala, sp. nov 81
- Cambrian glaciation 209
- Canal construction in Ohio 128
- **Carney, Frank**, Abandoned shorelines of the Oberlin Quadrangle, Ohio 101
    - Abandoned shorelines of the Vermilion Quadrangle, Ohio 233
    - Economic mineral products of Ohio 137
    - Geographic conditions in the early history of the Ohio country 403
    - Geologic development of Ohio 365
    - Glaciation in Ohio 183
    - Metamorphism of glacial deposits 1
    - Relief features of Ohio 381
    - Transportation in Ohio 125
- Case of pre-glacial stream diversion near St. Louisville, O 339
- Catazyga headi-schuchertana, Ulrich 32
- Catazyga uphami-australis, var. nov 31
- Cements in Ohio,—natural, Pozzuolane and Portland 156
- Chagrin river 393
- Chamberlin and Salisbury's Geology 1,7,9,193,205
- Cincinnati arch 374
- Clark, George Rodgers, campaign of 417
- **Clark, Howard**, A case of pre-glacial stream diversion near St. Louisville, Ohio 339

Page
Clay in Ohio . . . 170
Clay, properties of . . . 171
Clidophorus, sp . . . 73
Clitambonites rogersensis, Foerste . . . 69
Coal, origin of . . . 177
Coal in Ohio . . . 173
Conneaut creek . . . 392
Conodarcium richmondensis, sp. nov . . . 71
Contribution of Astronomy to general culture . . . 353
Crania granulosa-cumberlandensis, var. nov . . . 41
Cryptolithus tesselatus, Green . . . 78
Crytoceras hitzi, sp. nov . . . 78
Cuyahoga river . . . 394
Cyclocoelia crassiplicata, sp. nov . . . 36
Cycloelia ella, Hall . . . 36
Cycloelia sectrotiata, Ulrich . . . 37
Cycloelia sordida, Hall . . . 36
Cyrtocerina madisonensis, Miller . . . 74
DAVIS, W. M., reference to . . . 387,397
DAVISON, A. W., Thermo-electric Couples . . . 245
Dalmanites carleyi-rogersensis . . . 85
Devonian in Ohio . . . 13
Drainage cycles-Maumee, Whittlesey, Warren and Lake Erie base-levels . . . 114–7
Dunmore's Indian War . . . 417
Dytactospongia madisonensis, Foerste . . . 20
Earth origin, Nebular hypothesis . . . 368
Earth origin, Planetesimal hypothesis . . . 369
Economic mineral products of Ohio . . . 137
England's claim to Ohio . . . 411
Erie canal . . . 128
FOERSTE, AUG. F., Preliminary notes on Cincinnatian and Lexington fossils of Ohio, Indiana, Kentucky, and Tennessee . . . 17
FOOTE, Earl HARRINGTON, A study of the supposed hybrid of the black and shingle oaks . . . 315
French and Indian War . . . 412
French claim to Ohio . . . 409
FROST, EDWIN B., The contribution of astronomy to general culture . . . 353
Galvanometer, standardization of . . . 251
Geographic conditions in the early history of the Ohio country . . . 403
Geological relations of salt in Ohio . . . 151
George III's "royal domain" and the Quebec act . . . 413
Glacial erosion . . . 190
Glacial motion . . . 188
Glaciers, work done by . . . 190
Glass sand in Ohio . . . 153
Grand river . . . 393
Great Miami river . . . 396

Page
Hebertella alveata-richmondensis.... 55
Hebertella occidentalis, Hall.... 53
Hebertella sinuata, Hall.... 52
Hebertella subjugata, Hall.... 54
Hocking river.... 399
Huron river.... 395
Immigration routes to Ohio.... 126
Iron in Ohio.... 139
Iroquois Confederacy.... 408
Labechia (?) corrugata, sp. nov.... 86
Lake Erie drainage.... 392
Lake Erie, origin of.... 217
La Salle.... 406
Leptaena tenuistriata, Sowerby.... 45
Leptobolus lepis-cliftonensis, var. nov.... 21
Lime in Ohio and its uses.... 155
Lingula covingtonensis, Hall and Whitfield.... 22
Lingula modesta, Ulrich.... 22
Lingula waynesboroensis, sp. nov.... 23
Little Beaver river.... 400
Little Miami river.... 397
Lower Maumee stage of Maumee shoreline.... 103
Mahoning river.... 400
MARK, CLARA GOULD, The Mercer limestone and its associated rocks in the Newark-Zanesville region.... 267
Maumee river.... 396
Mercer limestone and its associated rocks in the Newark-Zanesville region. 267
Metamorphism.... 372
Metamorphism of glacial sediments of Pleistocene period in central New York and northern and central Ohio.... 1
Miami canal.... 128
Mississippian in Ohio.... 378
Mohawk route to Ohio.... 404
Muskingum river.... 399
National Road through Ohio.... 134
Natural gas in Ohio.... 158
Nebular hypothesis of LaPlace.... 368
Northwest Territory.... 420
Oberlin Quadrangle, Ohio, abandoned shorelines of.... 101
Ocean sediments.... 368
Ohio canal.... 128
Ohio, physiographic regions.... 384
Ohio river, development of.... 392
Ohio river drainage.... 396
Oil and gas, origin of.... 167
Oil in Ohio, early history.... 162
Opisthoptera concordensis, sp. nov.... 70

Page

Ordovician fossils.......... 89
Ordovician in Ohio.......... 376
Orothceras (Dawsonoceras) hammelli, sp. nov.......... 74
Orthoceras (Loxoceras) milleri, sp. nov.......... 76
Orthoceras (Ormoceras) hitzi, sp. nov.......... 77
Orthoceras (Spyroceras) bilineatum-frankfortensis, sp. nov.......... 75
Orthorhynchula linneyi, James.......... 24
Pasceolus camdenensis, sp. nov.......... 85
Peace of Paris, 1783.......... 418
Pennsylvanian in Ohio.......... 378
Permian glaciation.......... 209
Permian in Ohio.......... 379
Piracy, river.......... 386
Platystrophia acutilirata, Conrad.......... 65
Platystrophia clarksvillensis, sp. nov.......... 65
Platystrophia colbiensis, sp. nov.......... 55
Platystrophia colbiensis-mutata, var. nov.......... 56
Platystrophia colbiensis-precursor, var. nov.......... 57
Platystrophia crassa, James.......... 59
Platystrophia cypha, James.......... 61
Platystrophia laticosta, Meek.......... 58
Platystrophia morrowensis, James.......... 60
Platystrophia profundosulcata, Meek.......... 58
Plectorthis dichotoma, Hall.......... 49
Plectorthis equivalvis, Hall.......... 46
Plectorthis fissicosta, Hall.......... 48
Plectorthis jamesi, Hall.......... 50
Plectorthis neglecta, James.......... 52
Plectorthis plicatella, Hall.......... 49
Portage river.......... 395
Pottsville formation in Ohio.......... 267
Preliminary notes on Cincinnatian and Lexington fossils of Ohio, Indiana, Kentucky and Tennessee.......... 17
Properties of building-stone.......... 143
Proterozoic glaciation.......... 208
Pterinea (Caritodens) demissa, Conrad.......... 71
Quercus imbricaria, microscopic study of.......... 323
Quercus leana, historical sketch of.......... 315
Rafinesquina declivis, James.......... 43
Rafinesquina winchesterensis, sp. nov.......... 42
Relief features of Ohio.......... 381
Remote drainage of Ohio.......... 387
Rhynchotrema dentata, Hall.......... 29
Rhynchotrema dentata-arnheimensis.......... 27
River history.......... 385
River sediments.......... 374
Rocky river.......... 398

Page
Salt in Ohio 148
Salt, origin of 152
Sandusky river 395
Schizocrania filosa, Hall 40
Schizocrania rudis, Hall 40
Scioto river 397
SEFTON, LILY BELL, Standardization of well-water in the vicinity of Granville, Ohio 119
Shoreline features in vicinity of North Amherst 107
Shore lines, geographic influences of 229,243
Shore lines, post-glacial tilting of 230
Silurian in Ohio 377
St. Lawrence route to Ohio 404
Standardization of well-water in the vicinity of Granville, Ohio 119
Study of the supposed hybrid of the black and shingle oaks 315
Suecoceras inaequabile, Miller 73
Swazey observatory 347
Thermo-currents, cause of 249
Thermo-electric couples 245
Transportation in Ohio 125
Trematis fragilis, Ulrich 38
Trematis punctostriata, Hall 37
Upper Maumee stage of Maumee shoreline 102
Vermilion river 395
Virginia, claim to Ohio area 416
Virginian expedition to Ohio 407
Warren shoreline 111
Western route to Ohio 403
Whittlesey shoreline 106
WILSON, HERBERT C, The Swazey Observatory, Denison University 347
Zygospira cincinnatiensis, Meek 30
Zygospira modesta, Hall 29

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BULLETIN

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1. The Metamorphism of Glacial Deposits. By Frank Carney 1
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GRANVILLE, OHIO, JUNE, 1910

THE METAMORPHISM OF GLACIAL DEPOSITS.[1]

FRANK CARNEY

INTRODUCTION

FIELD DATA
- Color of the altered drift
- Its texture and structure
- Folding, jointing, faulting
- Weathering

AGENCIES OF ALTERATION
- Chemical
  - Saturated condition of sub-glacial sediments
  - Oxidation and deoxidation
  - Carbonation; hydration
- Pressure
  - Weight of superincumbent drift
  - Weight of superjacent ice
  - Due to hydration

SUMMARY

INTRODUCTION

Glacial drift metamorphosed to a conglomerate has been studied in several parts of the world. A detailed description of such a conglomerate in South Australia, identified as a Cambrian tillite, has recently appeared;[2] glacial formations of the same period have been studied in China.[3] In India,[4] Africa,[5] and South Australia,[4] glacial conglomerates of Permian age have been carefully investigated.

The present brief inquiry is confined to glacial sediments of the Pleistocene period. The conclusion arrived at, from a field study of these sediments in central New York and in northern and central Ohio, is that locally, at least, the alteration of a part of the drift is under way, that is, it has reached an appreciable stage of metamorphism; furthermore, that this fact may be used in differentiating the drifts of some of the Pleistocene epochs.

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[1] Published by permission of the Ohio Geological Survey, but the author is responsible for the opinions expressed. Read before Section E of the American Association for the Advancement of Science at Baltimore, 1908. Reprinted from the *Journal of Geology*, vol. XVII, No. 5, July-August, 1909.

[2] Rev. Walter Howchin, "Glacial Beds of Cambrian Age in South Australia," *Quart. Jour. Geolog. Soc.*, vol. LXIV (1908), pp. 234-59. The same author made a preliminary report in 1901, *Trans. Roy. Soc. of South Australia*, vol. XXV, p. 10.

[3] Willis, Blackwelder, and Sargent, *Research in China*, vol. I (1907). Carnegie Institution, Washington.

[4] C. D. White, *American Geologist*, vol. III (1889), pp. 306-11. Chamberlin and Salisbury, *Geology*, vol. II (1906), pp. 632-35.

[5] C. D. White, *op. cit.*, pp. 303-6. Chamberlin and Salisbury, *op. cit.*, pp. 635-38.

In this paper the term "metamorphism" includes all alterations concerned in the transition from degradational products to solid rock again.[6] It is not possible to observe many stages in this cycle because of the fact that so far as present investigation goes, the glacial periods are separated by long lapses of time, and because of the further fact that most phases of metamorphism require a physical environment that precludes observation.

FIELD DATA

The glacial deposits that occasioned this study are characterized by the following features:

1. *Color.*—All the unmodified drift concerned is bluish; it is felt that this is the constant color of the deposits because the observations were made either along stream banks that were being undercut, thus giving fresh exposures, or along shore cliffs where the waves are undermining the drift. In most of the exposures the color condition is emphasized by contact with drift which differs in color; the usual association is a yellow and sometimes oxidized horizon of more recent glacial accumulation beneath which is the zone of bluish drift. So far as can be ascertained, the color is not dependent upon the content of the drift. The surfaces of the included bowlders, large and small, and the entire matrix of clay, are uniformly of a bluish cast. This characterization applies equally to these deposits in widely separated parts of Ohio as well as throughout a considerable region of central New York. Because of a lithological difference in the rock formations that were eroded, as shown by a study of the bowlders and pebbles in the drift, one would expect some variation in color; this, however, is not the case.

2. *Texture and structure.*—As is the case with nearly all types of glacial deposits, we have here a great variety in texture. The till of some exposures is very fine, and quite free of even small bowlders; other exposures contain many, and large, erratics. More uniformity in texture, however, is found in the water-laid drift belonging to this study; usually, it is fine, even silty.

All these deposits apparently show the effects of great and long-continued pressure. They are dense in structure. This compactness is manifest in the angle at which the cliff-faces stand, not infrequently overhanging; also in the tendency of bowlders, showing on the surface of the cliffs, to hang even after more than half their mass has been exposed. In some cases I was able to satisfy myself, by tracing this hard horizon back from the cliff, that it constituted the proverbial "hard pan" of well-drillers. Furthermore, I have seen several dug wells being made, in which case there could be no doubt about the identity of this compact horizon and the bluish till.

---

[6] C. K. Leith, *Journal of Geology*, vol. XV (1907), p. 313.

3. *Obvious physical alteration.*—In several cliff-exposures the contact between this hard deposit and the superjacent drift is a series of sags and swells representing either an irregular deposition of the subjacent material or its unequal erosion later (fig. 1). But the relation of the inequalities precludes subaerial erosion; the irregular surface is either genetic, or it was produced by the erosion of over-riding ice.

Contortion and folding is observed particularly in the water-laid deposits (fig. 2). This alteration has been studied in material varying form silt to rather coarse sand. I have examined many exposures, both modified and unmodified, which show jointing and faulting (figs. 3, 4, 5). In no case was I able to show conclusively a displacement of more than three inches, and this maximum displacement was always in the water-laid drift. It is quite impossible to measure movement along a fault-plane involving only till. On the theory that every joint is a fault,[7] we may assume a displacement even though it cannot be measured. In all exposures of till thus altered, the joints are nearly vertical, and in systems (fig. 6). In the water-laid deposits this characterization is less clear. It should be stated, furthermore, that along most of the joint-planes or fault-planes there has taken place either a secondary alteration or a deposition from percolating water (fig. 2). In some cases this secondary deposit has weathered away more rapidly than the wall material; in others, less rapidly.

4. *Weathering.*—Leaching in a relatively short time removes carbonates, especially from surface deposits. Only at a considerable distance from the top do we often get evidence of carbonates in the superjacent drift. This leaching by ground water is the first step in the cementation process always going on at lower horizons. The bluish compressed drift invariably shows the presence of cal-

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[7] G. F. Becker, *Bulletin of the Geological Society of America*, vol. IV (1893), p. 72.

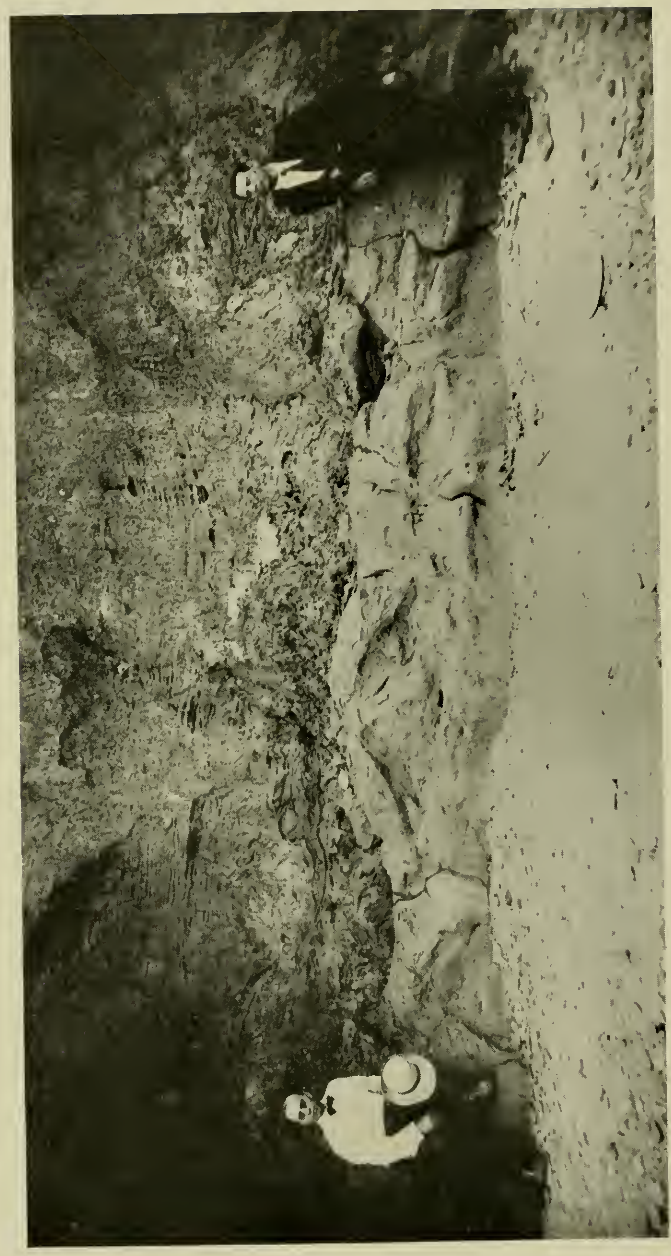

Fig. 1.—Buried valley west of Cleveland. At the base is bluish till, apparently ice-eroded; above is compressed and slightly distorted silt.

cium carbonate. This fact does not imply that the drift had never lost its carbonates through leaching; it means only that now this particular cement is present, deposited probably from solution. No further observation was made to determine the cements or other chemical content of this dense drift. It is tentatively assumed that the universal bluish color is a result of alteration, though it cannot be disproved that this drift in both New York and Ohio was not bluish from the time it was deposited, but the force of this possibility is somewhat lessened by the fact that there is considerable difference in the content of the drift of these areas; it is assumed, further, that this color probably represents a chemical alteration accompanying metamorphism, a change brought about, under particular conditions, by ground water in unconsolidated sediments. The nature of these conditions will be discussed later.

The superjacent yellow till usually shows the results of weathering, especially near the surface; but in all parts there is evidence of leaching.

AGENCIES OF ALTERATION

Normally most of the changes going on in the regolith are due to pressure and to chemical reactions. The pressure is that of the superincumbent mass which varies directly with the depth. Chemical reactions are chiefly associated with water which is always a solvent, but the water of glacial drainage, since it comes in contact with such a wide range of rocks, is highly solvent and has capacity for other chemical reactions.

Chemical.—Outside of arid regions, sediments contain a good deal of water. In all climates circulating ground water exists at some depth; the more humid the climate, the higher is the ground-water level. It is probable, however, that a special condition exists in sediments subjacent to an ice-cap; here, on account of the constant melting of the basal ice caused by radiation from the earth,[8] the supply of water is so great that a condition of saturation exists in these sediments. This condition of saturation was certainly the case during both the advance and retreat of the ice-sheet within the north-sloping side of the St. Lawrence drainage basin. This northward slope in conjunction with the wall of ice caused a ponded condition of drainage. Beneath these bordering lakes, sediments were always in a condition of saturation.

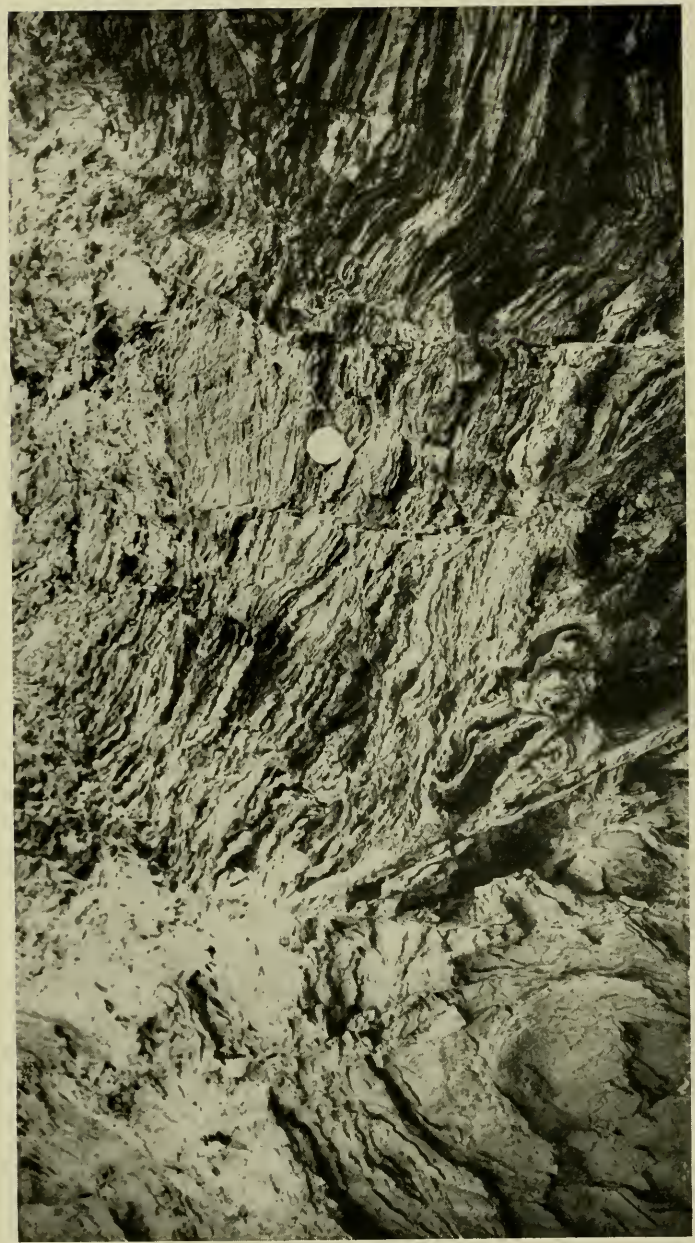

Fig. 2.—Deposits in a buried river valley west of Cleveland; this material was crumpled and distorted; later it was faulted; vein deposits occupy the fault-planes.

Underneath an ice-sheet, it is reasonable to suppose that oxidation is subdued, but even in the absence of atmosphere, sulphides may be slowly changed to sulphates. Since this glacially accumulated rubbish may contain constituents previously weathered, it is possible that deoxidation also takes place.

Throughout the distance between the Mohawk Valley in New York state and Michigan at the western end of Lake Erie, limestone formations come to the surface. These outcrops suffered degradation by the ice-sheet. Other limestone horizons farther north, in part of this distance, also contributed to the glacial load of debris. This content of limestone in glacial sediments was partly dissolved even by the cold water; no rock-forming constituent is more easily affected by water. The resulting carbonated water actively attacked the silicate minerals at least. Solution and later precipitation is always an accompaniment of ground-water circulating through glacial sediments, and further reactions will give different solutions.

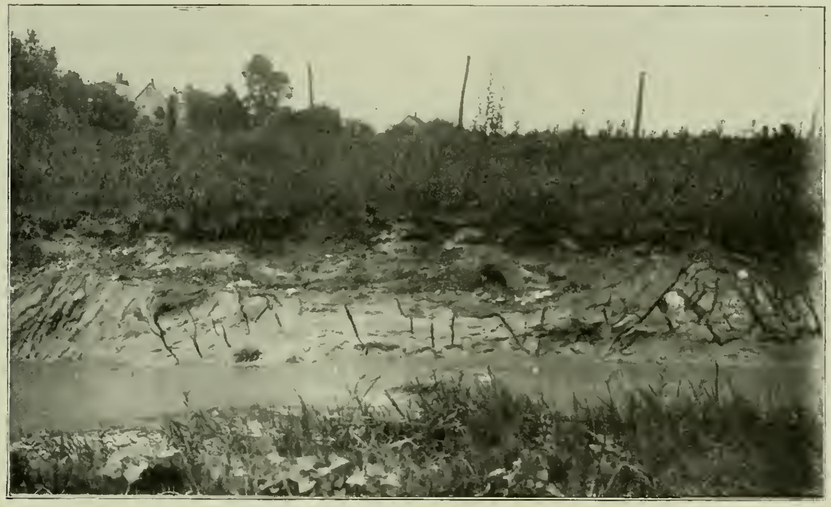

Fig. 3.—Disturbed and faulted bluish till exposed along Dugway Brook, Cleveland.

The decomposition of rock-constituents is usually accompanied by hydration. This is almost invariably the case in oxidation and carbonation. In unconsolidated materials beneath an ice-cap hydration would be an active agent in alteration.

[8] Chamberlin and Salisbury, *Geology*, vol. 1 (1904), p. 263.

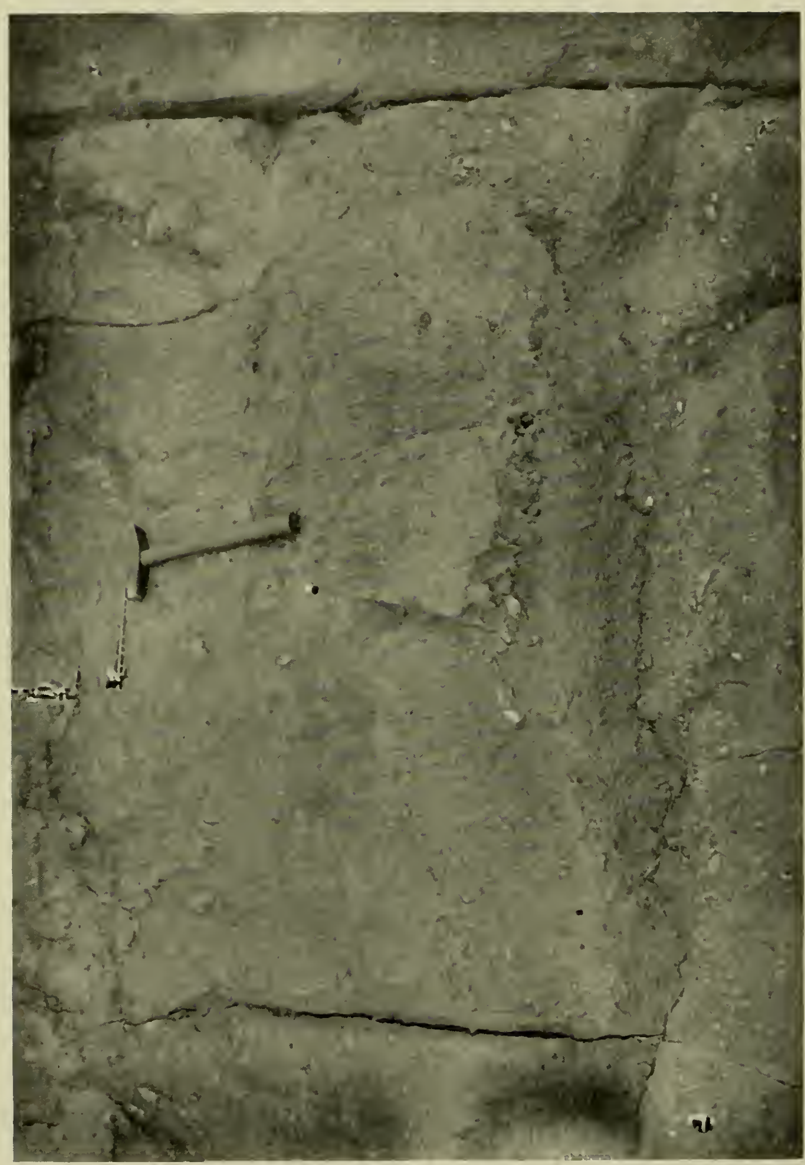

Fig. 4.—Jointed bluish till on shore of Lake Erie at Conneaut, Ohio. The cliff-face is a joint-plane at right angles to the two conspicuous joints.

Pressure.—In the deeper-seated areas of the fragmental zone of the earth's crust, pressure has long been regarded as playing an active part in the alteration of rock. In the case of the superficial sediments under discussion there appear to be three sources of pressure:

1. The weight of drift overlying a given horizon in a mass of sediments exercises a compressive force; in the deeper-buried sediments this force is stronger. In consequence of this compression there is greater facility in capillary action, that is, waters move more slowly through these sediments, and precipitation is increased.

2. During the continuance of an ice-invasion, the weight of the ice itself bore down on the unconsolidated materials, thus acting as a factor in their alteration. In discussing this, however, it must be granted that an ice-sheet degrades, first of all, the regolith. It is a fact nevertheless that in certain localities, some of the previously aggraded sediment was not removed by ice.[9] These deposits may be the drift of an earlier ice-invasion; in any case, wherever not removed, it was subject to the great weight of the ice-sheet. This weight can be computed only approximately. Some observations have been made on which are based conclusions in reference to the surface slope of ice-caps; this data includes a study of both existing ice areas and bands of drift constructed by former ice.[10] A conservative estimate of the depth of Wisconsin ice over the Erie basin is at least 2,000 feet. This figure is based on two considerations: the present difference in level between Lake Erie and altitudes south that were covered by ice is about 800 feet. The ice reached south of the Erie basin approximately 200 miles; if its surface sloped even six feet per mile, this would represent a depth of 1,200 feet which, plus the 800 feet due to the differenece in altitude, makes approximately 2,000 feet. The basal pressure per square foot for clear ice of this thickness would be 115,500 pounds.

In New York state, there is a greater difference in altitude, even when we neglect the overdeepened portions of the major Finger Lake valleys. The range in altitude alone would give 1,500 feet of ice; this, in connection with the surface slope of the ice, would give a depth of approximately 2,500 feet, which represents a basal

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[9] R. S. Tarr, *American Geologist*, vol. XXXIII (1904), p. 287. H. L. Fairchild, *Bulletin of the Geological Society of America*, vol. XVI (1905), pp. 53-55. F. Carney, *Journal of Geology*, vol. XV (1907), pp. 579, 580.

[10] Chamberlin and Salisbury, *Geology*, vol. III (1906), pp. 356-58.

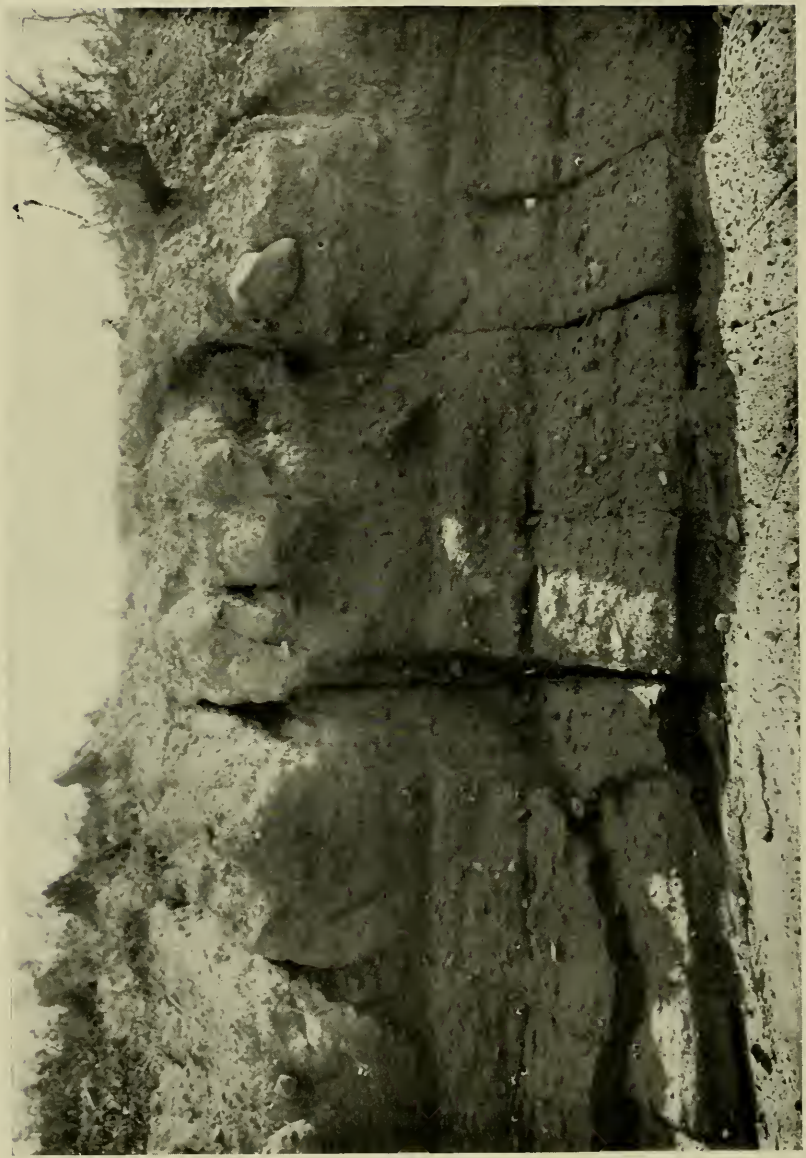

Fig. 5.—Jointed bluish till on shore of Lake Erie, east of Cleveland.

pressure per square foot of over 144,000 pounds. Both of these computations, it is noted, are for clear ice. Knowing that the ice-sheet must have carried constantly some drift, these figures undermeasure, perhaps, the real pressure. That the subjacent deposits would be compressed by the weight of this ice is undebatable.

Adams has shown that a condition of rock-flowage was induced in marble by a pressure of about 18,000 pounds per square inch.[11] The pressure on the sediments, as discussed above, is in either case more than 9,000 pounds per square inch.

Another possible factor associated with the question of pressure is the development of heat. Even the laggard motion of an ice-sheet represents energy which through basal interference is converted into heat. This heat may have no other manifestation than the wastage of ice near the friction zone. Whether a dead load upon compressible matter evolves heat in the absence of appreciable movements along planes developed in this matter is a question on which the writer is not informed.

3. It is thought, furthermore, that pressures are evolved by chemical changes going on in this drift. Such pressure is an accompaniment of hydration when the hydrated mineral is confined as must be the case in drift subjacent to a burden of at least 9,000 pounds per square inch. Other chemical changes also tend to increase the bulk of the minerals being altered.

SUMMARY.

In defining its age and origin the most suggestive feature of this drift is its color which is constant over widely separated areas. The folding, jointing, and faulting might be caused by Wisconsin ice readvancing over drift it had recently deposited; faulted sediments subjacent to till of such a readvance are shown in fig. 7.

It is possible that the bluish till is the product of the oncoming Wisconsin ice. If the pressure of an ice-cap is the most active agent of alteration, and the time factor is secondary, it is even probable that both the bluish and yellow drifts are Wisconsin; but the following observations tend to diminish this probability:

About three miles northeast of Newark, O., along Shanee Run, and again two and one-half miles southeast of Newark along Quarry Run, I have seen the same bluish till, at the former outcrop in contact with the yellow drift, at the latter showing only in the

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[11] F. D. Adams, *Bulletin Geological Society of America,* vol. XII (1901), p. 457.

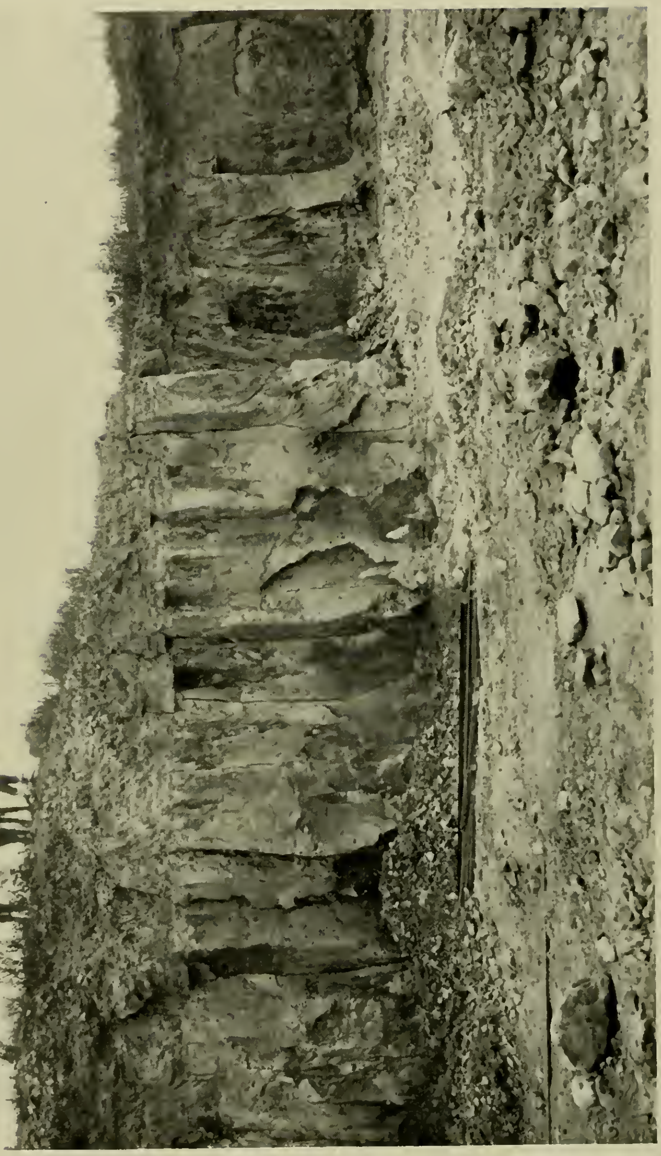

FIG. 6.—Water-laid drift overlying bluish till which contains two systems of vertical joints. This till is very stony, mostly limestone.

bed of the stream where it forms a riffle. These localities are just within the margin of the Wisconsin drift, where the ice was attenuated as well as short-lived. It is certain that in these two cases time has been the important factor in the alteration; no great mass of ice ever stood here for even a short period. If this hard bluish till was deposited by Wisconsin ice, its color is genetic; but on this hypothesis it is difficult to understand why the superjacent drift is yellowish, and the line of division is so sharp.

But there can be no question that the old valley of Rocky River, west of Cleveland, was buried by a pre-Wisconsin ice-invasion, presumably the Illinoian. The bluish till in this buried stream-course is apparently identical with the dense drift referred to in central Ohio and New York.

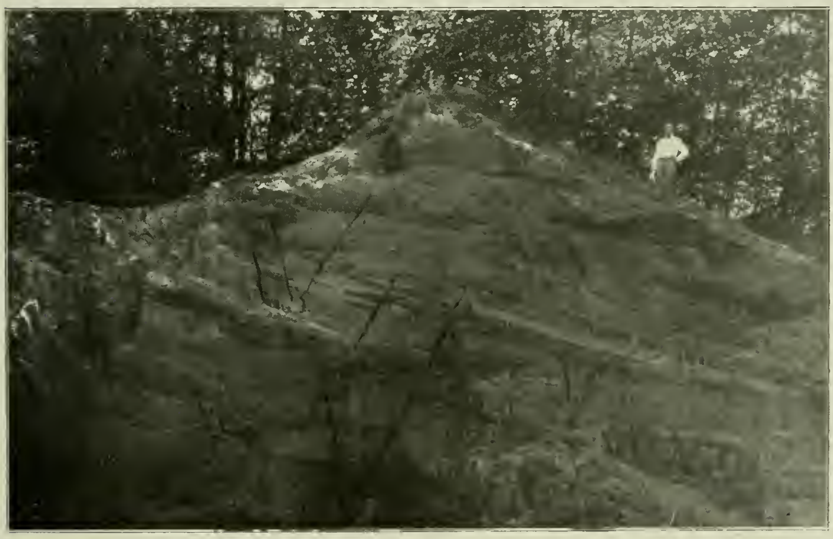

FIG. 7.—Faulted glacial gravels. Yellow till has been removed from the top.

These facts suggest the following conclusions:

1. Glacial deposits, regardless of their constituents, when buried for a long time appear to become compact, and bluish in color. This assumption does not disregard the possibility that some deposits have always been bluish. The dozens of exposures studied in both states show a great variety of rock-constituents, as well as wide variation in the general texture of the drift; this color is constantly noted in drift ranging from the fine silt to an ex-

tremely stony till (figs. 1, 2, and 6[12]). I have nowhere noted a gradual blending from one color to the other, nor streaks of the yellow penetrating the bluish, as has been described in the Central West.[13] It is very likely that upon sufficient exposure to weathering agents the blue till would become lighter in color; but because of its indurated condition it weathers less rapidly than does the superficial Wisconsin drift.

2. An ice-cap passing over glacial sediments, particularly till, develops in its joints and faults (figs. 2-4) either because the till on account of inconsistency in structure yields differentially to the weight, or because differential strains are induced by topography; these fracture lines are approximately vertical (figs. 5, 6). I have observed this jointed condition of till in central and northern Ohio, and in New York along creeks tributary to the outlet of Keuka Lake.[14]

3. The altered drift described in this paper contains abundant carbonates, probably deposited from circulating ground water, whereas carbonates are either absent or less conspicuous in the superjacent drift of later origin. This difference between the two drifts is apparent even when tests are made near their contact; the observation holds for exposures studied in all the areas under consideration.

4. The color in the case of the drift above described, its indurated condition, and the jointing appear to be associated with the change or metamorphism which develops tillite from glacial drift.

5. I believe that so far as the regions considered in this paper are concerned two Pleistocene epochs are indicated by a contact of the bluish and yellowish till.

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[12] Cf. *Journal of Geology*, vol. XV (1907), pp. 575, 577, for other pictures illustrating the same variation in texture.

[13] F. Leverett, *Monograph XLI*, U. S. Geolog. Surv. (1902), p. 272. *Ibid., Monograph XXXVIII*, U. S. Geolog. Surv. (1899), p. 28. W. H. Norton, *Iowa Geological Survey*, vol. IX (1898), pp. 480-82.

[14] *Journal of Geology*, vol. XV (1907), pp. 583, 584.

PRELIMINARY NOTES ON CINCINNATIAN AND LEXINGTON FOSSILS OF OHIO, INDIANA, KENTUCKY, AND TENNESSEE.

Aug. F. Foerste.

By far the best fossils for the accurate discrimination of the various Cincinnatian and Lexington horizons of the area of the Cincinnati geanticline are the bryozoans. Possibly, in the future, the ostracods may be of great service. If the brachiopoda, and some of the other more common groups of fossils are to be added to this list, a much more extended subdivision of forms, based upon slighter differences, will be necessary. It is not likely that such subdivisions of recognized species will commend themselves to those who are engaged in the broader problems of paleontology, but these subdivisions are necessary if all the available material is to be employed in the discrimination of the different faunas at the different horizons. Whether these subdivisions are to appear in literature as species or as varieties is another question. A great convenience of the Linnean binomial system is its restriction of names to two terms. This convenience is lost if too many terms appear under the trinomial form of varieties.

The Cincinnatian formations are rich in forms which are in the process of evolution, resulting in numerous groups within which the varieties are closely connected by abundant intermediate forms. In this wealth of material some investigators will see species where others see only varieties, or scarcely even the latter. In this case it will be well to remember that the object of the investigation will often determine the attitude of the investigator. The present paper is for the purpose of supplying material for the discrimination of Cincinnatian horizons.

Incidentally, it has been attempted to determine more accurately the type forms and horizons of some of the species already described. The best excuse for this preliminary publication of material is that it has already brought fruit in the renewal of investigations in the field from which former students, owing to other and more important interests, had departed.

The following classification of Cincinnatian and Lexington strata is here adopted:

Series	*Formations*	*Beds*
Cincinnatian	Richmond	Elkhorn
		Whitewater
		Saluda
		Liberty
		Waynesville
		Blanchester division
		Clarksville division
		Fort Ancient division
		Arnheim
		Oregonia division
		Sunset division
	Maysville	Mount Auburn
		Corryville
		Bellevue
		Fairmount
		Mount Hope
	Eden	McMicken or Paint Lick
		Southgate
		Economy
	Utica	Fulton
	Cynthiana	Nicholas
		Greendale
		Perryville
Upper Mohawkian	Lexington	Paris
		Wilmore
		Logana
		Curdsville

The Arnheim bed has been separated into two divisions, the upper or Oregonia division, exposed in the Blacksmith hollow, northeast of the railroad station at Oregonia, Ohio, being characterized by the introduction, at the base, of the characteristic Richmond fossils: *Leptaena richmondensis-precursor, Rhynchotrema dentata-arnheimensis*, and *Dinorthis carleyi*. On the eastern side of the Cincinnati geanticline, the lower half of the Arnheim is much less fossiliferous, and is terminated by a layer containing *Platystrophia ponderosa*. Southward, in Kentucky, this horizon consists of comparatively unfossiliferous argillaceous limestones, containing comparatively few specimens of this *Platystrophia*. A typical exposure is found about half a mile southwest of Sunset, along the road to Day's Mill, and from this locality the term Sunset division has been chosen for the lower Arnheim. It is suspected that this lower part has closer affinities with the Mount Auburn fauna than with the upper Arnheim.

The Saltillo limestone, characteristically exposed along the Tennessee river in Western Tennessee, was described in the January-February number of the Journal of Geology in 1903. It contains the following fauna:

Trematis punctostriata, Hall; *Schizocrania rudis,* Hall; *Leptaena tenuistriata,* Sowerby, var; *Leptobolus lepis-cliftonensis; Lingula waynesboroensis; Dalmanella; Zygospira recurvirostra,* Hall; *Clidophorus* sp., near *neglectus,* Hall; *Whiteavesia cincinnatiensis,* Hall and Whitfield; *Calymene platycephala.*

The Hermitage limestone, typically exposed in Davidson county, Tennessee, and thence southwestward, through Williamson and Maury counties, was accurately described by Hayes and Ulrich in their Columbia Folio, published in the fall of 1903. It appears to be the stratigraphical equivalent of the Saltillo limestone, and contains the following species, according to Ulrich:

Prasopora patera; Prasopora simulatrix; Leptobolus lepis; Dalmanella fertilis; Zygospira recurvirostra; Ctenodonta, small circular species: *Whiteavesia cincinnatiensis; Lophospira abnormis.*

The Logana limestone, typically exposed in Jessamine, Woodford, and Franklin counties, Kentucky, was described in the bulletin on the Lead and Zinc bearing rocks of Central Kentucky, by Prof. Arthur M. Miller, in 1905. It appears to be approximately equivalent to the Hermitage and Saltillo limestones of Tennessee, and contains the following fauna:

Lingula modesta, Ulrich; *Lingula covingtonensis,* Hall and Whitfield; *Trematis punctostriata,* Hall; *Cryptolithus tessellatus* (= *Trinucleus concentricus*).

Of the various species listed from the Saltillo, Hermitage, or Logana limestones, the following occur at Cincinnati, Ohio, in the lower fifty feet of rock there exposed, below the Fulton layer which contains the Triarthrus becki or Utica fauna:

Prasopora simulatrix; Lingula modesta; Lingula covingtonensis; Whiteavesia cincinnatiensis; Lophospira abnormis; Cryptolithus tessellatus; Schizocrania schucherti is regarded as closely related to *Schizocrania rudis,* and *Leptobolus lepis* evidently is related to the variety found in the Saltillo limestone.

Owing to the presence of similar or identical species in the lower 50 feet of rock exposed at Cincinnati, Ohio, and in the Saltillo, Hermitage, and Logana limestones of Tennessee and Kentucky, Dr. E. O. Ulrich is inclined to regard them all as approximately equivalent, an opinion which he finds fortified by the presence in the lower rocks at Cincinnati of various species, not here listed, which occur also in the Logana limestone.

Dystactospongia madisonensis, Foerste.

Along a branch of Laughery creek, a mile southwest of Ballstown, Indiana, the so-called shale bed, in the lower part of the Saluda section, is underlaid by four and a half feet of soft clayey material, and six feet of argillaceous rock with an abundance of *Tetradium minus* at various levels. This lower layer contains also *Rhynchotrema capax, Streptelasma vagans, Endoceras proteiforme*, the species of *Byssonychia* found at the same horizon two miles south of Versailles, and also *Dystactospongia madisonensis*. The latter was found about 2 feet from the top of this *Tetradium* section. *Dystactospongia madisonensis* occurs also in the upper part of the underlying section, a foot and a half thick, accompanied by *Calapoecia cribriformis; Tetradium minus* occurs occasionally in the lower part. The basal part of the section, nearly three feet thick, contains rather numerous large specimens of *Columnaria alveolata*, and *Strophomena planumbona*. *Dystactospongia madisonensis,* associated with *Calapoecia cribriformis,* and *Strophomena vetusta,* occur just below the *Tetradium* horizon also at the bridge east of Ballstown. The horizon for *Dystactospongia madisonensis*, therefor, appears to be at the base of the Saluda. The total thickness of the Saluda west of Ballstown is 56 feet. The upper half, 28 feet thick, is formed by the mottled limestone, which overlies the shale bed.

At the railroad cut west of Weisburg, only the base of the mottled limestone is exposed but here it contains numerous specimens of *Entomis madisonensis, Eurychilina, striatomarginata, Leperditia caecigena, Primitia cincinnatiensis,* and *Primitia milleri.* Beneath this level are 11 feet of clay, overlying a thin limestone layer containing *Strophomena sulcata, Streptelasma vagans* and *Streptelasma divaricans.* It is underlaid by 9 feet of limestone near the middle of which *Tetradium* occurs. The shale bed, six and a half feet thick, occurs at the base of the cut. The base of the

Saluda is not exposed. East of Weisburg, the total Liberty, with the exception of the extreme top is exposed.

Leptobolus lepis — cliftonensis, var. nov.

(Plate II, figs. 20 A,B,C.)

In the Saltillo limestone, at Clifton, Tennessee, there occurs a species of *Leptobolus* evidently closely related to *Leptobolus lepis,* Hall. Its outline is oval, or elliptical ovate, and pointed toward the beak of the pedicel valve. A sharply defined median septum extends from the anterior end of the pedicel groove forward almost to the center of the pedicel valve. This septum widens moderately, and is impressed along the median line by a sharp, narrow groove, also widening anteriorly. This results in two very narrow, subparallel grooves in the cast of this valve. The muscular impressions on each side of this median septum are limited anteriorly by a thickening of the interior of the shell which extends from the anterior end of the median septum laterally across the valve. Only a single narrow septal ridge is seen in the interior of a brachial valve, and this follows the median line of the shell to within a quarter of the length of the shell from its anterior edge.

No trace of lateral septal ridges was found in the brachial valves, and the septal ridges of the pedicel valve were not strongly divergent as in the specimens of *Leptobolus lepis* figured by Hall and Clarke. The Tennessee specimens agree more with figures 5 and 6, on plate 3, *New York Paleontology*, vol. VIII, figured by Hall and Clarke from Covington, Kentucky. But in the Tennessee specimens, the septal ridges and intermediate groove of the pedicel valve extend as far as the pedicel cavity, and are less divergent anteriorly. The color of the Tennessee specimens varies from dark brown to whitish, assuming the latter color in the coarser grained limestone layers which are interbedded with the finer grained limestones prevailing in the Saltillo bed.

If the figures presented by Hall and Clarke are correct in the details here mentioned, the Tennessee specimens are sufficiently distinct to merit at least a varietal designation.

A pedicel valve from the Fulton layer, west of Brent, Kentucky, agrees with figure 5, on plate 3,*New York Paleontology,* vol. VIII, in having the two septal ridges with the intermediate depression confined to the anterior part of the muscular area. The posterior part of this area, toward the pedicel groove, is smooth along the median part. The Tennessee specimens come from a much lower horizon.

Lingula modesta, Ulrich.

(Plate II, fig. 17.)

The type specimens of *Lingula modesta* were obtained from the Logana bed, at Frankfort, Kentucky. They are distinguished by their flatness, and the almost obsolete concentric striae. Specimens occasionally attain a length of 14 mm., and a width of 9 mm. In the larger specimens the lateral outline is gently convex, rounding moderately toward the beak, and more abruptly toward the anterior margin. This results in a form of outline which might be described as quadrangular ovate, in the case of the larger specimens.

Lingula covingtonensis, Hall and Whitfield.

(Plate V, figs. 5, 6.)

Lingula covingtonensis (fig. 5) was described from that part of the section at Covington, Kentucky, which lies between 25 and 50 feet above low water in the Ohio river. It is characterized by its elliptical form, the posterior extremity, at first sight, appearing almost equally rounded compared with the anterior. As a matter of fact, however, the rounding is more abrupt at the beak. The concentric striae are sharp and rather distant.

Lingula cobourgensis, as figured by Billings, is similar in form, though possibly slightly more elongate. Judging from the description, the concentric striae are fine and sharply elevated on each side of the beak, but more like fine concentric undulations of growth elsewhere. If that be a constant feature, *Lingula covingtonensis* differs in the sharpness of the concentric striae over the general body of the shell.

Specimens, identified as *Lingula covingtonensis,* occur in the Logana bed, at Frankfort, Kentucky (fig. 6). They agree in outline, and are characterized by the fine, sharp, rather distant concentric striae. The shell substance is whitish. In some of the specimens, the interior surface of the valves is irregularly pitted, the pits being arranged approximately parallel to the concentric markings belonging to the exterior. In these specimens, the concentric striae on the exterior are fine, sharp, and rather distant, as in other specimens from the same locality, also identified as *Lingula covingtonensis.*

Specimens pitted interiorly were described by Ulrich, from the strata a few feet above low water mark, at Covington, Kentucky, as *Lingula whitfieldi.* In the latter, however, the shell is stated to be relatively shorter, and broader in front, and the concentric striae are described as rather irregular and never so regularly disposed.

The type of *Lingula covingtonensis,* numbered 139 in the James collection at Chicago University, 12.6 mm. long and 10 mm. wide, is characterized by strong and rather equidistant concentric striae, between which the remaining concentric striae are much less conspicuous. It is preserved in a fine-grained limestone, the lower half of which is full of a small form of *Dalmanella* resembling *Dalmanella multisecta.* It evidently was obtained from the limestones several feet below the two-foot crinoidal layer which immediately underlies the Fulton horizon.

Lingula waynesboroensis, sp. nov.

(Plate II, fig. 18; Plate V, fig. 7.)

Three and a half miles northwest of Waynesboro, Tennessee, near the home of W. D. Helton on Beech creek, a species of *Lingula* occurs in the Saltillo limestone, closely resembling *Lingula briscis,* Billings, and *Lingula procteri,* Ulrich, in outline. The same species occurs also in the Saltillo bed, at Clifton, Tennessee.

The shell substance of this Tennessee species is white. The shell is very thin. The lateral outline is gently convex or subparallel anteriorly, converging gradually posteriorly toward the beak. Anteriorly, the lateral outline rounds into the anterior margin, and, the latter being less strongly convex, the outline of the shell is more oblong than oval. Concentric striae, very fine, and numerous, are separated by flat interspaces which usually are several times as wide as the striae, at least along the middle part of the shell, anteriorly. Radiating striae are usually absent, although extremely fine radiating striae may be noted occasionally. The interiors of pedicel valve occasionally have a low, broad septal elevation, extending slightly beyond the center of the shell; anteriorly, this elevation attains a width of about half a millimeter. A much narrower septal ridge occurs rarely in the brachial valve. In most of the specimens, no trace of these septal ridges was noticed. No other markings are shown by the interiors of the specimens at hand. Length, 13 mm.; width, 8.7 mm.

In *Lingula briseis,* Billings, the very fine longitudinal striae are characteristic, while the concentric markings are obscure. In *Lingula waynesboroensis,* the conditions are reversed.

Lingula procteri, Ulrich, is a larger and much thicker shell. It is much more robust in every way, and as a result the markings of the interiors of the valves are much better preserved, and in greater detail. Only concentric striae and more distant undulations of growth are mentioned in the original description, but obscure longitudinal markings appear to be present also, judging from the illustrations by Hall and Clarke. The outline of the shell also is more oval.

Orthorhynchula linneyi, James.

(Plate III, fig. 10.)

This species was described by U. P. James from specimens obtained by W. M. Linney in the Fairmount beds of Boyle county, Kentucky. It was listed from this horizon by W. M. Linney, in 1882, in his reports on Garrard, Lincoln, and Washington counties, and in his *Notes on the Rocks of Central Kentucky.* In his report on Clarke county, in 1884, Linney lists this species both from the Fairmount beds and from the Greendale division of the Cynthiana formation.

At the upper Fairmount horizon, *Orthorhynchula linneyi* is associated with *Escharopora hilli*, and *Cyrtoceras vallandinghami. Strophomena maysvillensis* occurs, although the chief horizon for this species is at the base of the Fairmount. An early variety of *Platystrophia ponderosa* also is found. Among other species may be mentioned: *Escharopora falciformis, Constellaria florida,* and *Phylloporina clathrata.*

Orthorhynchula linneyi is common in the upper Fairmount about a mile north of Paint Lick, in the southwestern corner of Madison county. It is abundant also at the bridge south of Redhouse station, in the northern part of this county; and about three miles west of Richmond, near the home of W. H. Parks. Three miles east of Junction City, half a mile from Givens station, near the northwestern edge of Lincoln county, it is less abundant. Several specimens are said to have been found by W. T. Knott about three miles southeast of Lebanon, on a branch of Caney creek, about a mile and a half north of the Lebanon-Bradfordsville road, south of the home of Richard D. Murrell. Since *Strophomena maysvillensis* is quite common in the lower part of this exposure, the specimens must have been obtained from the Fairmount.

Orthorhynchula linneyi is a characteristic member of the southern Fairmount fauna. It does not appear to occur north of a line connecting Clark with Washington and Marion counties, unless possibly as occasional, very rare specimens. Southward, however, it is very abundant. In southern Kentucky, along the Cumberland river, *Orthorhynchula linneyi* occurs in the Fairmount bed about two miles east of Rowena. Specimens of *Labechia ohioensis* occur 14 feet above the river. Small specimens of *Labechia ohioensis* and *Tetradium minus* occur 19 feet above the river. Both species are represented by good specimens 35 feet above the river. The intermediate strata, between 20 and 35 feet above the river, consist of limestone layers, 3 to 4 inches thick, interbedded with equal thicknesses of clayey layers, both richly fossiliferous. In these layers *Orthorhynchula linneyi* occurs associated with *Constellaria florida.* Farther up the river, sandy, strongly cross-bedded limestones occur below the horizons containing *Labechia* and *Tetradium.*

This association of *Orthorhynchula linneyi* with *Labechia* and *Tetradium,* in southern Kentucky, is characteristic of the upper Fairmount also in the area covered by the Columbia folio, in Tennessee. The lower Fairmount here is represented by richly fossiliferous strata containing *Strophomena maysvillensis.*

Orthorhynchula linneyi has been listed by Bassler also from the vicinity of Ben Hur, in the Powell Valley, in the southwestern corner of Virginia. Here it occurs in strata equivalent to the Fairmount, associated with *Platystrophia ponderosa* and *Modiolopsis modiolaris.*

Orthorhynchula linneyi is abundant also in the Cynthiana formation of Kentucky. Linney mentions it at this horizon in his report on Clark county. It is very abundant in Nicholas county, along the railroad between Pleasant Valley and Millersburg, and it occurs also at the Lower Blue Lick Springs. Specimens are very rare along the railroad between half a mile and two miles east of Colby, west of Winchester, in Clark county. Near Lexington and Versailles, specimens are rather common at some localities. It is abundant also along the path leading to the old reservoir southwest of Frankfort.

North of a line connecting Nicholas and Franklin counties, *Orthorhynchula linneyi* is very rare. In fact, it is very rare even in Scott and Harrison counties. A single well preserved specimen was found at railroad level at the base of the quarry west of Ivor, opposite Moscow, on the Ohio river. Another was found 10 feet above the railroad at the quarry east of Carnestown, about two miles farther up the river. It is very rare also at some localities in central Kentucky, for instance, along the railroad between the tunnel west of Million and Valley View, in Madison county.

In Tennessee, *Orthorhynchula linneyi* occurs in the Catheys formation to which the Cynthiana formation of Kentucky is essentially an exact equivalent. The underlying Bigby formation of Tennessee has been divided into two members in Kentucky. The upper member, in which *Hebertella frankfortensis* is common, is called the Paris member. The lower member, in which *Prasopora simulatrix* is common, is called the Wilmore member. As a matter of fact, *Hebertella frankfortensis* occurs also in the Wilmore bed, and a species of *Prasopora* closely similar to *Prasopora simulatrix* occurs in the Paris member, so that these two members are not well differentiated. The Logana bed of Kentucky is the Hermitage of Tennessee.

In Woodford county, Kentucky, one mile southeast of McKee ferry, and two miles south of the Crow distillery on Glenn creek, east of the road, near the home of Allen McGarvey, on the farm owned by Mrs. Ben Williams, *Orthorhynchula linneyi* is found in a very hard, fine grained, blue limestone below the Greendale member of the Cynthiana formation. This fine-grained limestone is regarded as the northern extension of the Perryville bed. In addition to *Orthorhynchula linneyi* it contains *Hebertella parksensis, Lophospira medialis, Lophospira bowdeni, Loxoceras milleri,* and *Isochilina jonesi*. This appears to be the Dove limestone of Safford's section at Nashville, Tennessee.

Whenever a species occurs at two horizons separated by a considerable interval, it is possible usually to detect at least some slight difference between the two sets of forms, representing the amount of change undergone by the species during the lapse of time represented by the interval. In the case of *Orthorhynchula linneyi*, a larger number of the Fairmount specimens have a more globose form, due to a less angular junction of the valves along the lateral margin, but more globose and more angular forms may be noticed at both horizons. The normal number of plications on the fold is four, but in the specimens from the Greendale division of the Cynthiana formation, at Pleasant Valley, the number is increased not infrequently, by intercalation, to five or six.

The muscular scar of the pedicel valve has a quadrate appearance due the parallel lateral outlines produced by the internal thickening of the shell on each side. It is of fairly large size. In a specimen having a length of 22 mm., the muscular scar had a width of 8 mm. and a length of 11 mm. The interior outline of the scar usually is moderately convex but may be nearly straight.

Rhynchotrema dentata — arnheimensis.

(Plate III, fig. 13.)

Rhynchotrema dentata-arnheimensis was found loose at the Arnheim horizon, a quarter of a mile east of Andersonville, and in situ at the same horizon half a mile south of Arnheim, and a mile and a half south of Russellville; all in Brown county, Ohio. In Kentucky, it occurs three miles south of Maysville; also at the Brown's run school house, two miles northeast of Rectorville and 8 miles southeast of Maysville; at the foot of the hill east of Wyoming, 30 miles south of Maysville; about a third of a mile southwest of Sunset, on the road to Day's mill; half a mile southwest of Howard mill, on the road over the hill to Spencer; a mile south of Indian Fields, and then two miles west, at the Curry bridge across Howard creek; four miles north of Richmond, at the railroad cut north of Ophelia; a mile north of Rowland, on the west side of Logan creek; near the Pleasant Valley church, southwest of Rush Branch post office; three miles southeast of Lebanon, a mile south of the home of P. L. Mudd, along a branch entering Caney creek from the east; a mile west of Lebanon, northwest of the home of Col. J. B. Wathen; half a mile north High Grove; a mile south of Smithville; near the home of J. D. Stansbury, a mile and a half south of Mount Washington; four miles southeast of Jeffersontown, where the road descends abruptly toward Floyd creek, a mile east of Shinks branch; three quarters of a mile west of Fisherville; and immediately south of Clay Village, at the northern foot of Jeptha Knob. At Jeptha Knob, this variety of *Rhynchotrema* occurs 945 feet above sea level, associated with *Platystrophia ponderosa*. At 985 feet *Dalmanella multisecta* is common, indicating a fault equivalent to the entire thickness of the Maysville formation. At Madison, Indiana, a single specimen of *Rhynchotrema dentata-arnheimensis* was found years ago by Mr. John Hammell, at the Arnheim horizon. So far, no specimens have been found in the Arnheim north of Madison, Indiana, or Andersonville, Ohio. Southward, in Tennessee, however, they occur at Goodlettsville, Newsom, and Clifton.

The horizon for *Rhynchotrema dentata-arnheimensis* is near the middle of the Arnheim bed, associated with *Dinorthis carleyi*, and above the *Leptaena richmondensis-precursor* horizon. At Madison, Indiana, *Platystrophia ponderosa* occurs near the lower end of the first railroad cut. *Leptaena richmondensis-precursor* is found 7.5 feet farther up. *Dinorthis carleyi* makes its appearance 4 feet above the latter, and is rather common for a distance of a foot and a half. The interval between the *Dinorthis carleyi* horizon and the top of the culvert at the upper end of the cut is 30 feet. At Arnheim, the lowest specimens of *Leptaena* occur 5 feet above the *Platystrophia ponderosa* layer. The vertical range of the *Leptaena* is three feet nine inches. *Rhynchotrema* occurs in the upper six inches of the *Leptaena* horizon, and is overlaid by the *Dinorthis carleyi* layer.

The strata containing *Leptaena richmondensis-precursor, Rhynchotrema dentata-arnheimensis*, and *Dinorthis carleyi* inaugurate a new fauna. They are the first representatives of the Richmond fauna among the brachiopods. From this horizon upward, the rocks usually are much more richly fossiliferous than those beneath, especially those beneath the *Platystrophia ponderosa* horizon. This is true especially southward and on the eastern side of the Cincinnati geanticline, in Mason, Fleming, and Bath counties. At Maysville, the upper, fossiliferous division of the Arnheim bed is 26 feet thick, the comparatively unfossiliferous argillaceous limestone layers beneath having a thickness of 16 feet. The latter represent an ingression of muddy sediments, similar to the later ingressions resulting in the formation of the Saluda and Elkhorn beds. For these, comparatively unfossiliferous argillaceous limestones, forming the lower half of the Arnheim section, as formerly defined, the term Sunset bed has been selected. This bed is well exposed southwest of Sunset, in Fleming county, on the road to Day's Mill. It contains occasional specimens of *Platystrophia ponderosa.* It is well exposed also at Wyoming, in Fleming county, where the base of the immediately overlying fossiliferous section contains *Leptaena richmondensis-precursor,* and *Rhynchotrema dentata-arnheimensis.*

Rhynchotrema dentata, Hall.

(Plate II, fig. 16; Plate III, fig. 12.)

Rhynochotrema dentata, as represented in the upper part of the Whitewater bed, at Richmond, Indiana (plate III, fig. 12), is characterized by the greater convexity of both valves. The middle part of the pedicel valve usually is not flattened and then partly reflexed toward the anterolateral angles, as is more frequently the case in large specimens of the Arnheim variety.

Zygospira modesta, Hall.

(Plate II, fig. 15 A,B.)

The type specimen, numbered 1356-1, preserved in the American Museum of Natural History in New York City, is 7.8 mm. long, 9.2 mm. wide, and 4.1 mm. thick. The pedicel valve has 18 distinct plications, and two indistinct ones, the latter being near the hinge margin. The four median plications are moderately elevated above the general convexity of the shell, and form a rather low, median elevation. The groove along the median line of this elevation is conspicuously wider than the two adjacent grooves. Corresponding to the median groove, the brachial valve has a comparatively strong median plication, while the two adjacent plications, one on each side, are distinctly narrower. A broad, but comparatively shallow depression extends from near the beak to the anterior margin of the shell; its lateral borders are not sharply defined but are formed approximately by the third plication on each side of the median plication. The specimen evidently was found in Cincinnatian rocks; it is labelled as coming from Cincinnati, Ohio, but this may mean merely that the specimen was obtained from some Cincinnati collection.

Similar specimens are found in the Fairmount bed at Cincinnati, and Hamilton, Ohio, and I have assumed the Fairmount as the type horizon.

The characteristic features of *Zygospira modesta* consist in the low median fold, and in the rather numerous lateral plications, all of them primary. In the type specimen there are 7 of these lateral plications on each side, but this number is frequently 8, and sometimes 9. Some of these specimens attain a length of 10 mm.

Zygospira cincinnatiensis, Meek.

(Plate VI, figs. 16 A, B.)

Zygospira cincinnatiensis was described by Meek as coming from an elevation of 250 feet above low water in the Ohio river, at Cincinnati, Ohio. *Strophomena planoconvexa, Dalmanella* (*Bathycoelia*) *bellula, Cyclocoelia ella* (= *sordida*), and *Plectorthis plicatella* are listed from 300 feet above the Ohio river. *Dalmanella multisecta* is said to range upward about 200 feet above low-water mark of the Ohio, and *Platystrophia laticosta,* probably including the form here described as *Platystrophia profundosulcata-hopensis,* is listed as coming from 250 to 300 feet above low-water in the Ohio. This suggests the Mount Hope bed for the origin of the type specimens of *Zygospira cincinnatiensis* as described by Meek. Unfortunately, the type specimen figured by Meek can no longer be found, and the series of specimens in the James collection at Chicago University numbered 164, and there labelled as types, evidently are from the upper Fairmount. In view of the fact that Meek's specimens were obtained from James, and considering the large size of the specimens studied and the more frequent disposition of the plications to bifurcate, as noted in the original description, it seems more likely that the specimens received by Meek were from the type series, and therefore also from the Fairmount. At the time James made his early collections, the horizons of many fossils was not known with the accuracy now considered desirable.

The specimens from the upper Fairmount, which are here regarded as typical, are distinguished from *Zygospira modesta* by the smaller number of primary lateral plications, usually 5 on each side of the median fold. In consequence the plications appear larger, more angular, and more distant from each other. The more prominent median elevation on the pedicel valve is due chiefly to the larger size of the individuals. The four primary plications on the median fold and the intermediate grooves have very much the same appearance as in *Zygospira modesta.* While the bifurcation of the primary plications, or the intercalation of additional ones, is the chief character usually relied upon in diagnosing this species, too much weight must not be given to this feature, since it is not constant, and numerous specimens may be collected at the typical horizon, in which there is no evidence of bifurcation. Among the four primary plications on the median fold, it is the lateral plications, and not the two median plications which frequently are bifurcated. Bifurcation of one or two of the lateral plications on each side of the median fold is not rare. Occasionally, even the two median plications on the fold are bifurcated toward the anterior margin of the shell, or one or two small plications are inserted near the anterior end of the median groove. Some of these specimens attain a length of 13 mm. Only the larger specimens are likely to show evidence of frequent bifurcation.

Although only a part of the specimens in the upper Fairmount show evidences of bifurcation it should be stated that it is only at this horizon that bifurcation becomes conspicuous. In the Mount Hope bed, at Cincinnati, Ohio, Vevay, Indiana, and a mile north of Mason, Kentucky, specimens occur with only 5 broad, angular, lateral plications, and with a prominent fold and distinct, broad sinus, but with no bifurcation of the plications. These specimens undoubtedly are the ancestral forms of typical *Zygospira cincinnatiensis* from the upper Fairmount. The type, however, originated already in the middle Eden, where specimens with 5 broad, angular lateral plications are found locally, for instance at Vevay, Indiana.

Catazyga uphami — australis, var. nov.

(Plate II, figs. 19 A,B; Plate III, figs. 14, A,B,C.)

In the Camp-nelson division of the High-bridge formation, at High Bridge, Kentucky, there is a species of *Catazyga* evidently closely related to *Catazyga uphami*, described from a somewhat higher horizon, in Minnesota. In Kentucky, this species of *Catazyga* is associated with *Orthis tricenaria, Hebertella bellarugosa,* and *Rafinesquina minnesotensis.*

The *Catazyga* from High Bridge, Kentucky, agrees with the typical form of *Catazyga uphami* in the number of radiating plications, about 60 on each valve. Since the intercalation of plications among those which may be regarded as primary is almost confined to the posterior third of the shell, it is evident that it is not the larger size of this shell, compared with *Zygospira recurvirostra*, which gives this *Catazyga* the appearance of having more plications than the latter species. Compared with typical *Catazyga uphami,* the specimens from High Bridge are broader, less elongate anteriorly, with a broad shallow depression on the anterior half of the pedicel valve, and a corresponding low elevation on the brachial valve. Since the absence of the sinus in the pedicel valve is characteristic of typical *Catazyga uphami,* the specimens from High Bridge may be regarded at least as a variety.

Catazyga headi — schuchertana, Ulrich.

(Plate II, fig. 3; Plate III, figs. 11 A, B, C.)

Catazyga headi was described by Billings from loose blocks of limestone, more or less erratic, found on the south side of the St. Lawrence river, opposite Three Rivers, seventy miles southwest of Quebec. The types described by Billings no longer can be identified among the material preserved in the Museum of the Canadian Geological Survey, but specimens collected by Whiteaves from the type locality are at hand and may be regarded as replacing the types. These specimens present the following characteristics.

Beak of pedicel valve slightly compressed laterally, the compression extending anteriorly as a faint elevation, the sides of which diverge at angles of about 12 degrees with the median line. Anterior to the center of the valve, the median part of this faint elevation is slightly depressed, forming a very faint and rather broad median depression. The brachial valve has a very faint median depression near the beak. Toward the anterior part of the valve there may be a faint median depression, a faint elevation, or neither, showing that these features can not be regarded as specific characteristics. The general appearance of the shell is well represented by the figures accompanying the original description. The lateral outline varies. The lateral outline usually is slightly straightened, even in the broadest specimens, but some specimens are distinctly compressed laterally, and then have a distinctly elongate appearance, resembling the form figured by Billings as variety *borealis.* With an abundance of material at hand, it appears impossible to distinguish these extremes of form as distinct species, or even as varieties. As a matter of fact, within certain limits, the species varies considerably in form at the same locality, in the same strata. At a distance of about 12 mm. from the beak there are about 7 radiating striae in a width of 3 mm.

Catazyga headi is represented along the northern line of outcrop of Cincinnatian strata, in Ohio, Indiana, and northern Kentucky, by a closely similar form. For this form, Mr. E. O. Ulrich proposed the name *Glassia schuchertana,* in the *American Geologist,* vol. 1, p. 186, in 1888, and added the following comments:

> This name is proposed for the shell figured and described by Meek in volume 1, *Ohio Paleontology,* page 127, plate XI, figures 1a-1d, under the name *Zygospira Headi,* Billings (sp.). Recent investigations of excellent material, belonging to Mr. Charles Schuchert's extensive collection of paleozoic brachiopods, show that our shell is distinct from the Canadian form, and that it possesses internal spires arranged precisely as in Davidson's new genus *Glassia.* Some of the specimens show further that the radiating striae which usually mark the surface are often very obscure and in rare cases entirely absent. Such smooth examples were collected near Versailles, Indiana.

Numerous specimens collected since the preceding lines were published indicate that well preserved specimens are not smooth but are covered with radiating lines which may be traced as far as the tip of the beak, as is also the case in typical specimens of *Catazyga headi* from the type locality in Canada. Smoothness results from weathering or exfoliation, and usually is noticed only in small specimens or toward the beak of larger specimens, although, occasionally, specimens 15 mm. in length which have been more or less weathered or exfoliated appear smooth until held transversely to the direction of some strong beam of light.

Specimens from Cincinnatian areas vary considerably in outline, as is true also in case of the specimens from Canada. Some are broad and some are narrow, resembling typical *Catazyga headi* and its variety *borealis*, as illustrated by the Ohio specimens figured by Hall and Clarke, 'but these forms are always intermingled in the same strata and can scarcely be said to represent even varieties. The subquadrate appearance of the shell, when seen from the brachial side, is due chiefly to the considerable lateral extension of the hingeline, and this is noticed even in the more narrow forms. The comparative straightening of the lateral outlines is shown chiefly by the broader specimens, but this is not a constant feature.

In attempting to distinguish between the Cincinnatian specimens and the typical specimens from Canada, the absence of a broad, though very shallow median depression along the anterior part of the pedicel valve of the Cincinnatian specimens has been seized upon. In addition to this, attention is called again to the tendency toward a subquadrate outline in case of the brachial valve, at least posteriorly, owing to the considerable lateral extension of the hinge-line. If these features do not prove comparatively constant for the Cincinnatian specimens, all attempt to distinguish them under a separate designation may prove of little value.

The internal markings, as might have been suspected, are closely similar to those of *Catazyga erratica*. The hinge-plate of the brachial valve consists of two stout processes separated by a sharp, narrow cleft, from each side of which the crural bases extend straight forward, separated by a distance of one millimeter at a distance of 2 mm. from their points of attachment. A low, flat median elevation extends forward, becoming tripartite at a distance of about 4 or 5 mm. from the beak, the middle division being longer, more narrow, and sharper. Exterior to each of the lateral divisions, an additional parallel low elevation is present. A short distance anterior to the pedicel cavity of the pedicel valve, a sharp, narrow median groove starts forward across the muscular area. On each side, posteriorly, there is a low elevation, broadening and thickening along the middle of the muscular area, narrowing again abruptly anteriorly, and bordered laterally at their distal extremities by a distinct and rather narrow depression. The thickening of the shell in the region of the muscular area terminates abruptly across the center of the valve. It is crossed by several radiate lines not mentioned in the preceding description.

The chief horizon for the Cincinnatian specimens of *Catazyga headi* is at the lower *Hebertella insculpta* horizon, at the base of the upper, or Blanchester division of the Waynesville bed, and in the immediately overlying and underlying strata. It is found at the base of the Blanchester division, immediately above *Hebertella insculpta*, along the creek a mile west of Blanchester, Ohio, and also a mile northeast of Woodville, along Stony creek, about three miles south of the Blanchester locality. It is common immediately above *Hebertella insculpta* in Adams county, Ohio, along a road crossing Eagle creek, a short distance south of the mouth of Gordon run, and at about the same horizon along a road crossing Suck run, three and a half miles southwest of Bentonville, a mile east of the Suck run school house. A single loose specimen of *Catazyga headi* was found east of Concord, in Lewis county, Kentucky. Several specimens have been found loose directly east of Wyoming, along the southwestern edge of Fleming county. At both of these Kentuckian exposures the specimens were found at the level of the middle, or Clarksville division of the Waynesville bed, but may easily have dropped from the base of the Blanchester division.

Along Sewell run, immediately south of the pike from Clarksville to Wilmington, in Clinton county, Ohio, Dr. George M. Austin found a considerable number of specimens from 6 to 10 feet below the lower *Hebertella insculpta* horizon, in the upper part of the Clarksville division. Along Stony Hollow, northwest of Clarksville, *Catazyga headi* occurs within two feet of the base of the lower *Hebertella insculpta* horizon, and a loose specimen occurred ten feet below this base. Hall and Clarke figure a specimen from the vicinity of Waynesville, Ohio. The species figured by Meek in the *Ohio Paleontology*, vol. 1, probably came from Clinton county.

Catazyga headi is listed from Richmond, Indiana, and probably was obtained a considerable distance down the river from this city. It occurs north of Versailles, being listed as *Glassia schuchertana* from this locality. At Madison, Indiana, *Catazyga headi* occurs along the Hitz road, directly west of the great railroad cut, 77 feet below the great *Columnaria* reef, here forming the base of the Saluda bed. Since the upper *Hebertella insculpta* layer, at the top of the Waynesville bed, occurs along the Michigan road 32 feet below this *Columnaria* layer, *Catazyga headi* must belong about 45 feet below the upper *Hebertella insculpta* layer. Since the Blanchester division of the Waynesville bed is not known to exceed 20 feet in thickness at Canaan and at Moores Hill, Indiana, it seems probable that at Madison *Catazyga headi* occurs in the upper part of the Clarksville division.

Judging from the preceding notes, *Catazyga headi* occurs in the upper part of the middle or Clarksville division of the Waynesville bed, and at the base of the upper or Blanchester division. In its geographical distribution, its range appears nearly coterminous with the area within which *Strophomena neglecta*, the most widely distributed fossil characteristic of the Blanchester division, has been recognized. It has not been found, so far, south of Wyoming, Kentucky, and Madison, Indiana.

Cyclocoelia sordida, Hall.

(Plate II, fig. 10; Plate VI, fig. 8 A, B.)

The type of *Cyclocoelia sordida,* Hall, (plate II, fig. 10,) preserved in the American Museum of Natural History, in New York City, possesses 21 primary plications and one secondary plication. The length of the specimen is 8.2 mm. and the thickness through the valves is about 4 mm.

The original description of *Cyclocoelia ella, Hall,* (plate II, fig. 11,) mentions 15 to 20 simple plications, but the first published illustrations of this species, in the *Fifteenth Report* of the New York State Cabinet of Natural History, plate 2, fig. 6, represents a specimen with at least 27 or 28 plications, and figure 7 represents a specimen with about 22 plications. Among the specimens preserved in the American Museum of Natural History in New York City, and numbered 1056-3, one specimen has 27 plications of which between 5 and 7 are intercalated within one millimeter of the beak; a second specimen has 21 plications; and three other specimens have 18 and 19 plications. *Cyclocoelia ella* is identical with *Cyclocoelia sordida.*

The specimens with 29 to 34 plications (plate VI, figs. 6 A, B, C, D, and 7 A, B, C, D) usually begin with about 21 primary plications, as in typical *Cyclocoelia sordida,* but the number of plications is increased by intercalation. These forms, here called *Cyclocoelia sordida-multiplicata,* appear intermediate between *Cyclocoelia sordida* and *Cyclocoelia sectostriata,* but the plications of the latter species appear more angular.

Cyclocoelia crassiplicata, sp. nov.

(Plate III, 16 A,B,C; Plate VI, figs. 9 A-C and 10 A-C.)

Among the specimens of *Cyclocoelia* found in the Fairmount bed at Cincinnati, Ohio, occurs a species, which is usually identified as *Cyclocoelia ella.* It possesses usually between 11 and 15 primary plications with occasionally several additional secondary plications, but the chief characteristic of this species consists not so much in the smaller number of plications as in their much greater prominence and angularity. This is especially noticeable in specimen possessing 18 plications, prominent and angular, while in a specimen of *Cyclocoelia ella* with only 18 plications, the latter are low, as in ordinary specimens of that species. Since the contrast between the two species consists chiefly in the much greater prominence of the plications in *Cyclocoelia crassiplicata*, the difference is much greater to the eye than indicated by the accompanying illustrations.

Cyclocoelia sectostriata, Ulrich.

(Plate III, figs. 15 A, B.)

Cyclocoelia sectostriata, Ulrich is something more than a multiplicate form of *Cyclocoelia ella*. About 21 plications originate sufficiently near the beak to be called primary. An approximately equal number is intercalated within 3 mm. of the beak, so as usually to alternate with the latter, and additional plications are intercalated anteriorly, bringing the total number up to about 50 in a specimen 8 mm. in length. The type, 10 mm. in length, was described as possessing 30 to 35 primary plications increasing to about 70 at the margin. Specimens of this type occur in the upper Fairmount. The specimen represented by figure 21, on plate 7, of the *Twentyfourth Report* on the New York State Cabinet of Natural History may belong here. The original specimen is preserved in the Dyer collection in the Museum of Comparative Zoology, at Harvard University, and is well represented by the published figure. The prominence of several of the median plications of the brachial valve may be an individual characteristic. The chief difference consists in the absence of additional intercalated plications toward the margin of the shell.

Trematis punctostriata, Hall.

(Plate V, fig. 1.)

Shell large, attaining a width of 30 mm.; nearly circular, width a little greater than the length. Brachial valve moderately convex, the convexity increasing toward the beak. Shell pitted, the pits arranged in radiating rows. Along the anterior half of the shell, and laterally, the pits are larger, and the rows are closer together. Eight to eleven rows occupy a width of two millimeters. The rows evidently increase by intercalation. Posteriorly, especially along the umbonal part of the shell, the radiating rows are more distant, and appear like narrow grooves crossing an otherwise comparatively flat surface. Each of these grooves is formed by a series of pits distinctly smaller than those on the anterior half of the shell. The distance from the beak at which the arrangement of pits in comparatively distant rows gradually merges into the arrangement in closely contiguous rows varies in different specimens. In some specimens, the rows become contiguous within 8 mm. from the beak; in others they remain distant even at 13 mm. from the beak. The type, figured by Hall and Clarke, was only a young specimen.

The type was found in the Saltillo limestone at Clifton, Tennessee, a short distance south of the Landing. Similar specimens occur in the Logana limestone at Frankfort, Kentucky. Both of these horizons are regarded as identical with the Hermitage of the area covered by the Columbia folio, in Tennessee.

Trematis ottawaensis, Billings is figured as having rows of pits in close juxtaposition even in the umbonal area toward the beak. There is no indication of flat interspaces on the posterior half of the shell. Shells of this type, I have not seen either in Kentucky or in Tennessee.

Trematis fragilis, Ulrich.

(Plate V, figs. 3, 4, 2.)

Trematis fragilis was described by Ulrich from the lowest beds of the Cincinnati group, a few miles south of Covington, on Bank Lick creek, Kentucky. According to Nickles, this places its horizon in the strata beneath the Fulton layer, in the argillaceous strata near the base of the section. Its chief characteristic is the limitation of the radiate lines of minute pits to the posterior part of the shell, chiefly posterior to a line crossing the shell transversely at the beak, although, in case of the pedicel valve, these rows of pits may be detected also for a short distance anterior to the foramen. These pits are too small to be detected without the aid of a lens. The shell, in general, appears smooth, modified in the case of the upper valve by wrinkles, some of them concentric, which may be due in part to vertical compression of the shell which usually is preserved in an argillaceous matrix. The shell of both valves is very thin, and the traces of original concentric markings usually are faint. The outline of the shell is nearly circular, slightly wider than long, and the upper valve is only moderately convex. The concavity of the cardinal slopes suggests that the beak was formerly distinctly elevated above the plane of the lower valve. The radiate lines of minute pits are separated by relatively wide, flat interspaces. The foraminal depression was 2.5 mm. long in a specimen having a length of 17 mm., but 24 mm. is mentioned as the average length of the shell. (plate v, figs. 3, 4.).

The specimen from which figure 8 on plate 1, of vol. 2 of the beak and along the margin of the shell almost as far as the anterior *Ohio Paleontology* was prepared is preserved in the American Museum of Natural History, in New York City. It is numbered 1335 - 2, and was identified by Hall and Whitfield provisionally with *Trematic punctostriata.* The punctae are very minute and can be recognized only under a lens. The punctae are distinct at the edge, but are absent from the greater part of the shell, forming the central and surrounding parts of the valve. Compared with the figure in the Ohio Paleontology, the rows of punctae are closer together, and the anterior outline of the shell is more rounded, and not straightened as figured, although wider than long. This specimen was referred by Ulrich to his *Trematis oblata,* in his original description of that species, possibly on the basis of the illustration in the Ohio Paleontology.

The specimen from which figure 9 on plate 1 of vol. 2 of the *Ohio Paleontology* was prepared and here illustrated by fig. 2 on plate v, forms No. 102 of the James Collection, at Chicago University. Its length is 15 mm. and its width is 15.2 mm. The foraminal depression is almost 3 mm. in length, and is V-shaped in form at its origin. The concentric striations are faint. The pits are minute, and are arranged in rows separated by relatively wide interspaces. They are restricted to the area posterior to a line running transversely across the shell at the anterior end of the pedicel notch. This specimen is regarded as belonging to *Trematis fragilis,* although it is not known from what horizon it was obtained.

Possibly the specimen represented by figure 8 in the *Ohio Paleontology,* described above, also may belong to *Trematis fragilis.* In *Trematis oblata* the pits become larger anteriorly, along the margin, and approach each other sufficiently to form a network; moreover, the shell has a distinctly ovate outline, the sides rounding rather abruptly into the anterior outline of the shell, which is distinctly less convex or even nearly straight.

Schizocrania rudis, Hall.

(Plate III, figs. 22 A, B.)

The type of *Schizocrania rudis* was found in the Saltillo limestone at Clifton, Tennessee. Its length was a little over 8 mm., and its width was about 13 mm. Judging from the illustration accompanying the original description, the specimen was imperfect posteriorly, and was flattened out laterally. The radiating striae are described as sharp, and flexuose.

In a second specimen, found by the writer at the same locality, the posterior outline on one side of the beak is well preserved, and is shown not to be concave, but rounded as in oval forms of *Schizocrania filosa,* and the beak is considerably more prominent than in that species. The length of the specimen is 11 mm., the width is 10 mm., and the number of radiating striations varies from 6 to 8 in a width of 2 mm. The striae are not flexuose except where affected by the distortion of the specimen, due to crushing. The fuller, more prominent beak, and the more conspicuous and more distant radiating striae will serve to distinguish this species from *Schizocrania filosa.*

Schizocrania schucherti, Hall and Clarke, from strata beneath the Fulton horizon at Covington, Kentucky, may prove to be much more closely related to *Schizocrania rudis* than suspected at the time when the posterior margin of the shell was believed to be concave on each side of the beak. According to E. O. Ulrich, this lower horizon at Cincinnati contains a fauna including elements closely similar to that of the Hermitage in Tennessee, to which the Saltillo limestone appears to be equivalent.

Schizocrania filosa, Hall.

Schizocrania filosa was described from the Trenton, at Middleville, New York, and the figures accompanying the original description are circular in outline. A specimen from the Trenton at Trenton Falls, New York, is figured by Hall and Clarke as oval in form.

On the south side of the Kentucky river, in Madison county, opposite Ford, the top of the Paris division of the Lexington limestone is 35 feet above the level of the railroad. Sixty feet below the level of the railroad, or 95 feet below the top of the Paris bed, is the top of a series of fine-grained blue limestones referred to the Wilmore bed. That part of fine-grained limestone section which is above river level has a thickness of 16 feet. It contains *Modiolodon oviformis, Rhynchotrema inequivalve,* a variety of *Hebertella frankfortensis* with more numerous radiating plications than in the typical form, *Liospira vitruvia, Lophospira medialis,* and *Schizocrania filosa.* This *Schizocrania filosa* is oval in form, narrower posteriorly. The length of a well preserved specimen is 16 mm., its width is 15 mm., and the convexity of the dorsal valve is about 3 mm. Radiating striae numerous, about 12 in a width of 2 mm. Posterior adductor scars large, similar in form to those represented in figure 26, plate IV G, in the *Paleontology of New York,* vol. VIII, by Hall and Clarke from the Maysville formation at Cincinnati, Ohio. The anterior edge of the scars extends to 6.5 mm. from the beak. The anterior adductors are small, and are 8 mm. from the beak, and 4 mm. from each other.

Schizocrania filosa occurs in the Wilmore bed, and recurs in the Maysville formations, being known from the Fairmount, Bellevue, and Corryville beds.

Crania granulosa — cumberlandensis, var. nov.

(Plate V, fig. 8.)

A mile and a quarter southwest of Cumberland City, Tennessee, along the railroad, about half a mile south of the crossing of the Erin pike, a species of *Crania* occurs associated with *Dinorthis deflecta, Orthis tricenaria, Dalmanella subaequata, Strophomena incurvata, Rafinesquina minnesotensis,* and other fossils belonging to the Stones River Group. In Kentucky, equivalent strata occur at High Bridge, where a similar assemblage of fossils occurs in the Camp-nelson division of the High-bridge formation.

The specimens of *Crania* resemble in outline and size some of the specimens of *Crania scabiosa.* Some of the specimens attain a length of 10 mm. and a width of 12 mm. The outline, in general, is rounded, but the anterior margin usually is more or less straightened. The surface of the upper valve is of medium convexity, and the apex is rather blunt. Compared with *Crania setigera,* from about the same horizon in the northern states of the Mississippi valley, the granules are much more numerous. Compared with *Crania granulosa*, the shell is larger, less orbicular in outline, and the granules are more or less elongated, as though the bases of setae. While the granules are scattered, there is a tendency toward arrangement in more or less radiating lines. *Crania granulosa* occurs in the northern states of the Mississippi valley in strata which are equivalent to the lower strata exposed at High Bridge, Kentucky, and at Wells creek, in Tennessee. The Wells creek specimens of *Crania* therefore may be much more closely related to *Crania granulosa* than their size and general outline would indicate.

Rafinesquina winchesterensis, sp. nov.

(Plate V, figs. 13 A,B,C.)

In the Greendale division of the Cynthiana formation, east of the Cincinnati geanticline, between Nicholas county and Madison county, in Kentucky, forms of *Rafinesquina* with relatively narrow widths are common.

In the form for which the term *Rafinesquina winchesterensis* has been selected, the posterior outline is quadrate, the sides either being parallel or converging slightly toward the hinge-line. Along the anterior margin, the outline is evenly rounded. In the typical forms, the length nearly equals, or even slightly exceeds the width, producing an elongate appearance. However, specimens in which the length equals only nine-tenths of the width are common. The earlier stages of the shell, including about two-thirds of its length when mature, are moderately convex, but the anterior third of the more mature shell is curved downward so as to give a decidedly convex appearance on anterior or lateral view. In one specimen, 31 mm. long and 32 mm. wide, the convexity is 10 mm. The hinge-area of the pedicel valve is large; 2 mm. in height at the beak, and parallel to the plane of the brachial valve. In the typical shells, the radiating striations alternate more or less in size, especially from the umbo to one-third the length of the shell from the beak. The muscular area of the pedicel valve is indistinctly defined anteriorly. The muscular area of the brachial valve presents the same features as most forms of *Rafinesquina* from the overlying Cincinnatian rocks. In specimens 31 mm. long, the thickness of the shell through the valves is 6 to 7 mm.

Forms possessing these characteristics are found between Pleasant Valley and Millersburg, between Colby and Winchester, at

Greendale north of Lexington, and between Million and Valley View.

The narrower, more typical forms of *Rafinesquina winchesterensis* are accompanied by others in which the width is somewhat greater, the posterior outline, however, remaining quadrate (plate v, figs. 14, 15 A,B). In these specimens the length usually equals nine-tenths of the width or less. These specimens usually have a less convex appearance, especially anteriorly. In a specimen 35 mm. long and 39 mm. wide, the convexity was 7 mm., and the thickness of the shell through the valves 4.5 mm. In these specimens the radiating striae of the pedicel valve are distinctly finer, especially along the posterior half of the shell, although becoming larger and alternating in size near and anterior to the middle. The striae of the brachial valve also are finer. For these flatter, finely striated forms, the term *filistriata* has been selected. As a matter of fact, some of the narrower, more convex specimens, resembling typical *Rafinesquina winchesterensis* in form, have numerous fine striae, but intermediate forms are to be expected in any attempt to differentiate the *Rafinesquinae*.

Rafinesquina fracta, compared with *Rafinesquina winchesterensis*, is a larger, flatter, and much thinner shell, although possessing a similar outline.

Specimens of *Rafinesquina* from the Eden formation, between Rogers Gap and Sadieville, agree with the variety *filistriata* in outline, but are thinner, and there is a distinct difference in the size of the striae, one to three finer striae being intercalated between the much more prominent primary ones. A similar alternation is faintly indicated on the brachial valve. The median plication may be slightly more distinct.

Rafinesquina declivis, James.

(Plate II, fig. 4; Plate V, figs. 12 A,B,C,D.)

The following description of *Rafinesquina declivis*, under the generic term *Strophomena*, was published by U. P. James in the *Cincinnati Quarterly Journal of Science*, vol. 1, p. 240, in 1874:

> This shell is remarkable for the manner in which it is arched or bent over. Cardinal line of the ventral valve straight; area narrow; beak slightly projecting; cardinal line pointed at the extremities, extending, apparently, beyond the width of the shell below (owing to the sudden depression or curve of the lateral margins, directly forward of the points of the cardinal line, it has

this feature); lateral and front margins bent over at nearly right angles with the plane of the exterior of the valve. Shell slightly convex from the beak to the extremities of the cardinal line, and about two-thirds of the distance from the beak to the front, giving to the umbonal convex surface a subtriangular form. More than half the area of the shell is bent suddenly over. Surface covered by rounded radiating striae, a central and strong one more prominent than the others; about every fourth or fifth stria larger than the ones between; crossed by fine concentric lines. Striae increased by interstitial addition. Dorsal valve not observed.

Width, measuring along the cardinal line, seven-eighths of an inch; length about the same.

Position and locality—Cincinnati Group, near Boyd's station, on the Kentucky Central Railroad, about 30 miles south of Cincinnati.

Collected by U. P. James.

In the James collection, preserved in the Walker Museum at Chicago University, a series of specimens, numbered 2392, is labelled as forming the types of *Rafinesquina declivis,* James. Of these, the specimen here represented on plate V by figures 12 A, B. is regarded as the one originally described. It is characterized by the sudden downward flexure of the lateral margins of the shell resulting in a subtriangular form. It is this downward flexure which suggested the term *declivis.* The choice of this term is unfortunate since the strong downward curvature of the sides of the shell and the triangular form of the specimen here regarded as the one first described are due to the lateral compression and contortion of the containing rock, a very argillaceous, fine-grained limestone. All of the specimens belonging to the so-called series of types evidently were obtained from the same locality, the railroad cut a quarter of a mile north of the station, where the massive argillaceous limestone rises to a height of 25 feet above the railroad. This limestone lies directly below the base of the Eden formation. *Dalmanella multisecta* and a species of *Leptaena* occur within 11 feet of the base of the Eden. All of the specimens of *Rafinesquina declivis* in the series of types are characterized by the prominence of the median striation, and by the distinctness of every fourth, fifth or sixth one of the other radiating striae. However, several of the specimens have the sides and anterior portion only moderately deflected, and the specimen represented by figure 12 D, and another specimen not figured, do not even have the triangular form. In fact, figure 12 D probably represents the normal, not distorted, form of *Rafinesquina declivis,* although some of the specimens evidently were a little longer compared with the width at the hinge-line. In addition to *Rafinesquina declivis,* the rock at Boyd's station contains *Ceratopsis intermedia,* Ulrich.

Leptaena tenuistriata, Sowerby.

The following description of *Leptaena tenuistriata* was published by Sowerby in Murchison's *Silurian System,* vol. 2, p. 636, and illustrated by figure 2a on plate 22, in 1839:

> Semicylindrical, closely striated; top of the upper (pedicel) valve with 12 or more concentric rugae, convex; sides expanded.
>
> A shell much resembling *L. depressa,* and about the same size, but ornamented with much closer striae and of a thinner substance.
>
> Locality—Marloes Bay; Narbeth, Pembrokeshire; also at Gaerfawr in the Caradoc Sandstone of Montgomeryshire.

In the accompanying figure, 14 radiating striae are figured as occupying a width of 4 mm. The shell, viewed from above, is rather quadrate in appearance, the concentric wrinkles approaching the hinge-line nearly at right angles, and there being no conspicuous extension of the shell along the hinge-line. The main body of the pedicel valve is comparatively flat, the geniculate border bending abruptly downward. The concentric wrinkles are well defined.

In *Leptaena richmondensis* (this Bulletin, vol. xiv, plate iv, figs. 10 A,B), from the Richmond of Ohio, Indiana, and Kentucky, identified by Hall as *Leptaena tenuistriata,* the number of radiating striae often is only 9 in a width of 4 mm., the shell is shorter, and is conspicuously elongated along the hinge-line, the width frequently equalling twice the length. Moreover, the downward flexure of the geniculate border is less abrupt. The radiating striae are broad, separated by sharp, narrow grooves, and resemble pieces of cord in close juxtaposition.

In the Saltillo bed, at Clifton, Tennessee, a single small valve of a *Leptaena* was found (plate v, figs. 9 A,B), which resembles *Leptaena tenuistriata* in having 14 radiating striations in a width of 4 mm. These striae are rather sharp, and are separated by grooves equal in width to the striae. The concentric wrinkles are only moderately conspicuous. The body of the pedicel valve is comparatively flat, and the flexure at the comparatively short geniculate border is fairly abrupt. The shell is relatively shorter and broader than in the figure of the type specimen. Its length is about 11.5 mm., and its width, 18mm. While not identical with *Leptaena tenuistriata,* from the Caradoc of England, it probably is more closely related to this species than is *Leptaena richmondensis,* which frequently is identified with the Caradoc species.

The Saltillo limestone is identical with the Hermitage limestone of the area covered by the Columbia folio, in Tennessee, and with the Logana of Kentucky.

The *Leptaena* from the Saltillo limestone is interesting chiefly because it indicates one of the earliest appearances of this genus in strata whose equivalent can be recognized in Kentucky. *Leptaena charlottae,* of Minnesota, may be an earlier form.

The succession of forms, in descending order, is as follows:

Leptaena richmondensis............Waynesville to Whitewater.
Leptaena richmondensis-precursor....Arnheim.
Leptaena gibbosa, James...........Economy.
Leptaena invenusta................Fulton or Lower Economy.
Leptaena tenuistriata, var..........Saltillo (Logana).

Plectorthis equivalvis, Hall.

(Plate II, figs. 13 A,B; Plate VI, figs. 17 A,B, 2,3.)

Plectorthis equivalvis was described by Hall from the Cincinnatian series at Cincinnati, Ohio, and a specimen from the Trenton at Middleville, New York, was doubtfully referred to the same species. The type specimen, from which figures 6 a to c, on plate 32, of the *New York Paleontology* was prepared, is not listed among the types preserved in the American Museum of Natural History in New York City, but a specimen bearing one of the green tags used by Hall to indicate his types occurs among a group, numbered 4490 and labelled *Plectorthis fissicosta,* and appears to have been the specimen used in the original description of *Plectorthis equivalvis.*

The length of this specimen is 15 mm., the width across the middle is 16 mm., the length of the hinge-line is 13 mm., and the thickness or depth of the shell is 8.3 mm. The contraction in front of the hinge-line is considerably less than is indicated in the drawings accompanying the original description, but similar errors occur in other figures on the same plate. The foramen is not exposed. The number of primary plications is about 20, increasing soon to 23, and about 6 millimeters from the anterior margin of the shell these primary plications are supplemented on each side by a secondary plication, thus forming fascicles of plications, consisting in each case of three plications, the primary plication being more conspicuous than the other two. The surface of the shell is not clean. A certain quantity of foreign matter attached to the shell gave rise, in the original description, to the statement that the strong radiating plications are marked as if by the bases of short spines, or of squamose projections of the shell, which, in perfect specimens, indicate a character much like *Atrypa aspera.* This was a most unfortunate comparison, and readily accounts for the failure readily to identify this shell, once it had become separated from its original label. No other shell occurs in the Hall collection which even approximately resembles the outline of his *Plectorthis equivalvis.*

Plectorthis equivalvis belongs to one extreme of a group of shells which is very abundant in the Fairmount bed at Cincinnati, and vicinity. Usually the width is distinctly greater than the length, in the ratio of 10 to 8 or 7 (plate VI, figs. 3, 2). The tendency toward a trifid arrangement of plications is marked, but frequently only one of the secondary plications is present between two primary plications, and the term bifid, used in Hall's original description, becomes appropriate. Toward the anterior margin of the shell, the secondary plications are less conspicuously depressed below the level of the primary ones than in *Plectorthis fissicosta,* and this is their chief difference.

In a large suite of specimens from the Fairmount at Cincinnati, Ohio, considerable variation in the relative width of the shell may be noticed. Narrow individuals occur, but there appears to be no evidence that these occur regularly enough to be considered a variety. Apparently the narrow form selected as the type of *Plectorthis equivalvis* by Hall is representative only of individual variation, not of group variation. It is merely an individual specimen which has not grown to its full size laterally. Specimens of this type are never found in numbers at some one locality or horizon, but singly and widely separated. It is only when specimens from widely different localities and from different horizons are selected and brought together that the impression can be produced that there is a variety in which the shell is narrow. With the exception of very few specimens, the species proper consists of broad, not of narrow shells, and to these broad shells the name *Plectorthis equivalvis* should be applied even if the original type specimen was a narrow form.

It is needless at this late date to state that *Plectorthis equivalvis* is not present in any part of the Trenton of New York or elsewhere.

Plectorthis fissicosta, Hall.

(Plate VI, fig. 4.)

(Plectorthis fissicosta, type, this Bulletin, vol. XIV, pl. IV, fig. 5 A,B.)

The type of *Plectorthis fissicosta,* Hall, preserved in the American Museum of Natural History, and numbered 4490, agrees very well with the original description and with the general appearance of the accompanying figures. The length of this type specimen is 16.5 mm., the width is 21 mm., and the thickness probably was about 8.5 mm., but the latter can not be determined accurately since the specimen is crushed. There are 20 primary plications, of which 11 show the so-called fission of the plications very well, and 2 only poorly. The postero-lateral plications appear narrower and remain simple. The secondary plications are added about 9 mm. from the beak. Together with the primary plications they form groups or fascicles, each consisting of three plications among which the primary plications are much more elevated and more conspicuous. In the case of two fascicles, in case of this type, there are 4 plications, instead of 3, present.

Specimens of this type are rare in the upper part of the Fairmount bed at Cincinnati, Ohio, and occur as far west as Vevay, Indiana.

Plectorthis triplicatella, Meek, is founded upon a shell possessing the same characteristics, and this name should be dropped for the prior one, *Plectorthis fissicosta,* Hall.

Plectorthis fissicosta is a variety or direct descendant of the normal broad-shelled forms of *Plectorthis equivalvis,* of which the narrow specimen used as a type is only an individual variation. *Plectorthis fissicosta* is characterized by the great prominence of the primary plications, causing them to appear widely separated, especially along the middle parts of the shell. The secondary plications are intercalated at a considerable distance from the beak, thus adding to the appearance of the primary plications being separated by deep grooves. These features are possessed, although in a less accentuated degree, also by the specimen represented by figures 9 f, g, on plate 32, *New York Paleontology,* vol. 1, and there included as one of the forms of *Plectorthis plicatella.* This specimen, preserved in the American Museum of Natural History and numbered 695-2, is not well represented by the published figure. The secondary plications are not added until within slightly less than a third of the distance from the anterior edge. Together with the primary plications, they form fascicles each consisting of three plications. The primary plications are not as prominent as in typical *Plectorthis fissicosta.*

Plectorthis plicatella, Hall.

(Plate VI, figs. 5 A,B.)

The types of *Plectorthis plicatella*, numbered 695-2, and preserved in the American Museum of Natural History in New York City, were obtained from the Fairmount at Cincinnati, Ohio. In this species, the young specimens usually have simple primary plications only, and specimens of this character may occasionally attain a width of 20 to 23 mm. Usually, however, large specimens show at least a trace of secondary plications at a distance of about 9 to 10 mm. from the beak, although these may be still comparatively obscure 13 mm. from the beak.

If this interpretation of the species be correct, *Plectorthis equivalvis* and *Plectorthis fissicosta* differ from *Plectorthis plicatella* chiefly in the distance from the beak at which the secondary plications make their appearance and in the relative prominence of the primary plications compared with the secondary ones.

The group, *Plectorthis plicatella, Pl. equivalvis, Pl. fissicosta,* characterizes the typical Fairmount fauna of Ohio, Indiana, and the immediately adjacent part of Kentucky. The southern Fairmount fauna, characterized by *Strophomena maysvillensis* and *Orthorhynchula linneyi*, may be termed the *Maury fauna,* since it is well represented in the so-called Leipers formation of Maury county, in Tennessee. This southern fauna extends northward across Cumberland river, and central Kentucky, toward the northern part of the latter state, and northeastward into the Alleghanies.

Plectorthis plicatella-trentonensis, from the Trenton of Minnesota (*Minnesota Paleontology*, vol. III, plate 33, fig. 5 to 7), and Wisconsin, is more constant in the absence of secondary plications, even in specimens attaining a length of 14 mm. It appears to be the stock from which the Fairmount species of the Cincinnatian areas were derived.

Plectorthis dichotoma, Hall.

The figures accompanying the original description suggest that the type of Plectorthis dichotoma was characterized by about 20 primary plications alternating with an equal number of secondary plications, except possibly at the postero-lateral angles of the shell. The secondary plications are distinctly less conspicuous and are added about half way from the beak of the anterior margin. The grooves between the primary and secondary plications are relatively wide, and are distinctly marked by concentric striations.

Specimens possessing these features may be selected from among the numerous individuals belonging to the broad form of *Plectorthis equivalvis* found in the upper Fairmount, west of Dillsboro station, in Indiana (plate V, fig. 16 A, B, C, D). In these specimens both the brachial and the pedicel valve appear less convex than in the broad form of *Platystrophia equivalvis* which abounds at Cincinnati, but it must be remembered that Hall compared his *Plectorthis dichotoma* not with this broad form but with the narrow individual used by him as a type. Compared with the type of *Plectorthis fissicosta*, the plications appear more numerous, and the entire shell less robust. Similar specimens occur at Cincinnati.

In the original description of *Plectorthis dichotoma*, however, the number of primary plications is given as 26 and these are stated to bifurcate uniformly half way from the beak to the anterior margin. The accompanying illustrations suggest that the number 26 may have been a misprint for 20, but as a matter of fact the number of primary plications frequently reaches 24 to 26 when there are no intercalated secondary plications near the postero-lateral angles. The emphasis on the regular dichotomous branching of the plications does not assist much in view of the fact that the increase in the number of plications is always by intercalation and not by dichotomous branching, and this intercalation is distinctly illustrated by the accompanying figures. The type of *Plectorthis dichotoma* has been lost.

Plectorthis jamesi, Hall.

(Plate II, figs. 9 A,B.)

The description of *Plectorthis jamesi* appears to have been based upon the series of specimens, numbered 4489, preserved in the American Museum of Natural History in New York City, and there labelled as the types. Among these, the largest specimen was figured by Hall and Whitfield, in the *Ohio Paleontology*, vol. 2, plate 1, figs. 21, 22, as the largest one of the type specimens. It has about 23 primary plications, increasing to about 50 at the margin, chiefly by the intercalation of additional plications toward the anterior margin. The cardinal extremities are compressed vertically, and the lateral margin forms an angle of about 85 degrees with the hinge line. The sides of the ventral valve are somewhat flattened, and the middle is a little depressed toward the front. The area of this valve is only moderately inclined backward.

As a matter of fact, several of the specimens in this series of types undoubtedly belong to *Plectorthis neglecta.* These are the specimens which have given rise to the following parts of the original description:

> Cardinal extremities usually truncate or *rounded*: Dorsal valve convex, becoming *gibbous*, with a shallow often scarcely defined *sinuosity* in the middle; middle of the ventral valve sometimes a little depressed towards the front.

Occasionally *Plectorthis neglecta* is distinctly sinuous along the anterior margin, due to a slight elevation along the median parts of the brachial valve, anteriorly, and to a corresponding flattening or depression of the pedicel valve. This inclusion of typical specimens of *Plectorthis neglecta* among the types of *Plectorthis jamesi* suggests either that the type of *Plectorthis dichotoma* was lost as long ago as 1861, or that the latter species was not identical with *Plectorthis neglecta.*

Associated with these specimens of the *Plectorthis neglecta* type, in this series of types described as *Plectorthis jamesi,* are a number of smaller specimens, which seem to have been regarded as the young of *Plectorthis jamesi,* and to have inspired the following parts of the original description:

> Often the striae are *simple throughout*, and, when well preserved, are always marked by fine thread-like concentric striae, and towards the margin by a few lamellae of growth; this species in general form, *resembles Orthis plicatella;* but the area is much larger, and extends to the salient cardinal extremities; while in that species the extremities are usually rounded and the shell a little rounded below.

These smaller specimens belong in the Corryville bed, 100 feet above the *Plectorthis neglecta* horizon. Local collectors at Cincinnati have usually regarded these smaller specimens as the true types of *Plestorthis jamesi,* notwithstanding the fact that they are described in the second and third paragraphs of the original description, while the large specimen figured by Hall and Whitfield and the specimens of *Plectorthis neglecta*, already mentioned as occurring among the series of types, formed the basis of the first paragraph of the description. *Plectorthis neglecta* is found in the Mount Hope bed, but very similar specimens occur in the lower Corryville east of Maineville, in Warren county, Ohio. It is possible that the large figured specimen also is a Corryville form. Its chief feature is the extended width of the shell along the hinge-line, the postero-lateral angles equalling about 85 degrees. In other respects the shell resembles some of the forms of *Plectorthis* found in the Fairmount bed (plate VI, fig. 2).

Plectorthis neglecta, James.

(Plate VI, figs. 1 A-E.)

Figure 21, plate V, of the *New York Paleontology*, vol. VIII, labelled *Plectorthis dichotoma,* is the interior of the Mount Hope species, *Plectorthis neglecta,* James.

The types of *Plectorthis neglecta,* numbered 2399, are preserved in the James collection, in Walker Museum at Chicago University. In this species the intercalation of secondary plications often begins within 3 or 4 mm. from the beak and additional plications may be added near the anterior margin. The secondary plications soon attain about the same height and width as the primary plications, so that the shell in general has a more closely and uniformly plicated appearance than any other species of Plectorthis found near Cincinnati. The grooves between the primary and secondary plications are narrow. Not infrequently the anterior half of the pedicel valve is slightly depressed or flattened.

Plectorthis neglecta makes its appearance in the Mount Hope bed, at Cincinnati, and extends at the same horizon southwestward to Vevay, Indiana, and southward to Mason, Kentucky. It distinctly precedes *Plectorthis plicatella* of the Fairmount, and must belong to a different line of descent.

Plectorthis dichotoma may be identical with *Plectorthis neglecta,* but in the absence of the type and in the presence of the figure accompanying the original illustration, this appears doubtful. It is unfortunate that among the numerous types in the Hall collection, the apparently aberrant types, *Plectorthis equivalvis* and *Plectorthis dichotoma,* should be missing or at least not definitely identified in the collections as types of these species. Under these conditions it might be preferable to abandon the doubtful term *Plectorthis dichotoma* for the definite one *Plectorthis neglecta.*

Hebertella sinuata, Hall.

(Plate II, fig. 5.)

Hebertella sinuata differs from *Hebertella occidentalis* chiefly in the absence of the slight median depression near the beak of the ventral valve. Moreover, in the typical forms, the primary plications are distinctly coarser along the posterior half of the shell. Owing to bifurcation, these plications may appear less coarse near the anterior margin of the shell. The small specimen represented by figs. 2 a, g, i, n, on plate 32 B, of the *New York Paleontology*, vol. 1, is too small to show the characteristics of the species very well, and the originals of 2b and c can not be identified. On this account, the original of figures 2 d, h, k, and o have been selected for illustration in this paper.

Specimens of this type occur throughout the Richmond, and are especially common in the upper part of the Waynesville bed, but forms identical in character appear as low as the Bellevue, and in the upper Fairmount. The types are labelled as coming from Cincinnati, Ohio, but their original source and horizon is not definitely known.

In the original description it is stated that *Hebertella sinuata* occurs at Maysville, Kentucky, and at Cincinnati, Ohio, but that it is less frequently found at Oxford, Ohio, and at Madison, Indiana. This favors the Maysville formation as the source of the types.

Since the median depression near the beak of the brachial valve usually is too faint to be readily seen, and since it occurs both on shells having plications of medium size and on those having coarse plications, it appears doubtful whether the absence of this slight depression is sufficient to give name to a separate variety, especially in the Maysville representatives, although in the upper Waynesville and in the Liberty this feature becomes more constant. Moreover, it is difficult to differentiate between *Hebertella sinuata* and *Hebertella occidentalis* on the basis of the coarseness of the primary plications, except in the case of selected specimens. At the same locality all the intermediate stages are almost certain to be found. However, the discriminations proposed by Hall are of interest. These forms of *Hebertella* belong to what might be called a series of nascent species, not yet fully differentiated, corresponding to the numerous variations in the genera *Platystrophia*, *Plectorthis*, *Cyclocoelia*, and *Rafinesquina* during Maysville time.

Hebertella occidentalis, Hall.

(Plate II, figs. 1, 2.)

The chief characteristic of *Hebertella occidentalis* is the slight median depression near the beak of the brachial valve, which disappears anteriorly. The radiating striae are of medium coarseness, compared with those selected as types of *Hebertella sinuata* and *Hebertella subjugata*. Specimens of this type are fairly common in the Richmond, ranging from the Arnheim to the Elkhorn, but they are especially common in the Liberty bed and in the upper part of the Waynesville. Forms apparently identical in character appear as low as the Corryville and upper Fairmount. It is not known from what horizon the types were obtained. They are labelled as coming from Cincinnati, Ohio, but this labelling frequently was used for specimens obtained from Richmond strata by the Cincinnati collectors.

In the original description, *Hebertella occidentalis* is cited from Maysville, Kentucky, Cincinnati and Oxford, Ohio, and Madison, Indiana. The Maysville and Cincinnati exposures probably were both in the Maysville formation. The Oxford and Madison specimens probably came from Richmond strata. This favors the source of the type specimens from the Maysville formation.

The specimen represented by figs. 2a, g, i, on plate 32 A, of the *New York Paleontology*, vol. 1, is too small to show the characteristic features of the species, as described, very well, and the originals of figs. 2b and d can not be identified. Therefore the specimen illustrated by figs. 2 c, k, and the one illustrated by figure o, on the same plate have been selected for illustration in the present paper.

Hebertella subjugata, Hall.

(Plate II, fig. 8.)

Hebertella subjugata differs from *Hebertella occidentalis* and *Hebertella sinuata* chiefly in the finer plications. There is no median depression near the beak of the brachial valve.

Specimens of this type are common in the lower and middle Eden, as exposed between Sadieville and Rogers Gap, and both east and west of Million, in Kentucky. At Cincinnati, similar specimens range from the Mount Hope bed upward through the Maysville, being more common in the lower beds. It occurs also in the Waynesville bed, and probably higher in the Richmond.

In the original description of this species, Cincinnati and Oxford, Ohio, Maysville, Kentucky, and Madison, Indiana, are mentioned. This favors the Maysville formation as the source of the types, since the latter are labelled as coming from Cincinnati, Ohio.

Hebertella subjugata, in the Eden, appears to be a direct descendant of *Hebertella parksensis*, from the Greendale division of the Cynthiana formation. *Hebertella occidentalis* is regarded as a descendant of *Hebertella subjugata*, with *Hebertella sinuata* as another derivative.

Hebertella alveata — richmondensis.

(Plate V, fig. 10.)

In typical *Hebertella alveata* (this Bulletin, vol. XIV, plate IV, fig. 8A), the shell is considerably wider along the hinge-line than anteriorly, the postero-lateral angles being acute. In the variety *richmondensis*, plate V, fig. 10, the hinge-line is considerably shorter than the width of the shell across the middle, the postero-lateral angles are rounded, and the brachial valve is strongly convex, especially in the umbonal region. Both forms occur in the upper part of the Whitewater bed, at Richmond, Indiana, accompanied by intermediate forms (plate V, fig. 17). It is very doubtful whether the forms with a very short hinge-line should be distinguished even as a variety. *Hebertella alveata* makes its appearance already in the Liberty bed, although *Hebertella occidentalis*, characterized by the slight median depression at the beak of the brachial valve, disappearing anteriorly, is far more common there.

Platystrophia colbiensis, sp. nov.

(Plate IV, figs. 2 A, B.)

In the Cynthiana formation, between Colby and Winchester, in Kentucky, a small form of *Platystrophia* occurs in which the median fold is only moderately elevated, and not strongly compressed laterally, while the sinus is broad and shallow. Four plications occupy the fold, and three occur in the sinus. The number of lateral plications on each side of the fold varies usually from 8 to 9. The hinge-line may equal the width of the shell across the middle, but usually is a little shorter. The convexity of the shell is considerable, but rarely enough to be called gibbous. Owing to the small elevation of the fold, the brachial valve has a more evenly convex appearance than the small forms of *Platystrophia* occurring in the Mount Hope bed, and described by Meek under the term *Platystrophia profundo-sulcata* (*Ohio Paleontology*, vol. 1, plate 10, fig. 2 a-d). The length of a typical specimen is 13.5 mm.; the width, 19 mm.; the thickness through the valves, 12 mm.; the elevation of the fold above the general convexity, slightly over one millimeter.

Specimens bearing these characteristics occur in the Greendale division of the Cynthiana bed at Pleasant Valley, and at the Lower Blue Lick Springs, in Nicholas county, and thence southwestward to Millersburg, Paris, and Lexington; along the railroad between Colby and Winchester; between Million tunnel and Valley View, all in Kentucky.

Similar specimens occur in the Paris bed at Lexington, Frankfort, and Drennan Springs, Kentucky. A small *Platystrophia* occurs 20 feet above the Ohio river, at Carnestown, Kentucky, associated with *Strophomena vicina*, in beds possibly equivalent to the Paris bed. Small specimens of *Platystrophia* occur also along the railroad between Rogers Gap and Sadieville, Kentucky, in strata containing *Clitambonites rogersensis*.

Platystrophia colbiensis-mutata, var. nov.

(Plate IV, figs. 3 A, B.)

By selection, it is possible to differentiate from among numerous specimens of *Platystrophia colbiensis* a much smaller number of individuals in which the number of plications on the fold is increased to six or more plications. Usually two initial plications are increased to four near the beak, and two additional plications are added on the sides of the fold within a third of the length of the shell from the beak, thus resulting in six plications. If any additional plications are present, these are added to the exterior side of the inner pair. Shells of this form are larger, broader, and less convex. The fission of the plications is confined to the fold, those on the sides remaining simple. In a typical specimen 15 mm. long, the width was 20 mm., the thickness through the valves 12 mm. The number of plications on the fold was 6, and 11 occurred on each side. In one specimen, 9 plications are found on the fold.

Specimens possessing these features are found at Pleasant Valley, and five miles west of Winchester, Kentucky.

In *Platystrophia fissicostata*, McCoy, the fission of the plications occurs on the sides of the shell as well as on the fold. *Platy-*

strophia reversata, Foerste, from the Brassfield or Clinton bed of Ohio is another mutation in which the fission of the plications is confined to the fold and sinus.

Platystrophia colbiensis — precursor, var. nov

(Plate IV, fig. 1.)

By selection from a large number of *Platystrophia colbiensis,* it is possible to differentiate a series of specimens characterized by a larger size, greater width, less convexity, in which the posterior part of the shell along the hinge-line frequently is slightly extended beyond the width of the shell across the middle. The width of an average sized specimen is 27 mm.; the length, 19 mm.; the convexity, 14 mm. Four plications occupy the fold, and 8 to 10 are found on the sides.

Specimens having these characteristics occur between Colby and Winchester, and also at various localities between Millersburg and Pleasant Valley, Kentucky. Specimens in which the hinge-line is slightly shorter than the width across the middle of the shell also occur.

Specimens of *Platystrophia ponderosa* make their appearance as early as the upper part of the Fairmount bed, associated with *Orthorhynchula linneyi,* along the eastern side of the Cincinnati geanticline, from Lincoln to Clark county. They may be traced at this horizon as far north as Maysville, Kentucky. Both forms with the hinge-line slightly longer than the width across the middle of the shell, and those with shorter hinge-lines occur one mile north of Paint Lick. These specimens differ from typical *Platystrophia ponderosa* chiefly in their smaller size. Specimens an inch and a quarter wide, resembling *Platystrophia ponderosa,* occur also just beneath the massive Garrard sandy limestones at the George Million locality, southeast of Million, Kentucky, and similar specimens are found near the base of the Upper Eden at Maysville. These lower specimens agree with *Platystrophia ponderosa* in possessing a low fold not laterally compressed, the number of plications being four on the fold, increasing occasionally to 5 or 6. If these forms actually belong to the *Platystrophia ponderosa* series, as they appear to do, the latter species may be of indigenous origin, and may have been derived from the larger varieties of the *Platystrophia colbiensis* type of shell.

Platystrophia profundosulcata, Meek.

(Plate VI, figs. 15 A-C.)

Platystrophia profundosulcata is a much smaller shell than *Platystrophia laticosta* and occurs usually at a lower horizon. It is very abundant at some localities in the lower Fairmount, especially near Cincinnati, Ohio, although numerous specimens occur also in the Mount Hope. In typical specimens, the sinus is much deeper and the fold stronger than in typical specimens of *Platystrophia laticosta* of the same size. Mature specimens average about 18 mm. in width. The length equals between seven and eight-tenths of the width, and the thickness varies between six and eight-tenths of the width. The hinge-line frequently is shorter than the width of the shell across the middle, but may equal the latter or even slightly exceed it. Specimens in which the lateral plications of the fold and sinus are almost or entirely obsolete are rare. Viewed from the side, the shell has a rather gibbous appearance. Usually 6 or 7 plications occur on each side of the fold, but specimens with 5 plications are not rare.

The specimens from the Mount Hope bed (plate IV, fig. 4) are closely similar to those from the lower Fairmount, but usually have the fold less strongly elevated and the sinus less profound. They are wider, and less convex. The width frequently reaches 20 mm. The number of plications usually is 6 or 7 but may vary from 5 to 10. At the Mount Hope horizon, this species usually occurs alone, not associated with any other form of *Platystrophia*. In the Fairmount, it may be associated with *Platystrophia laticosta*.

Platystrophia laticosta, Meek.

(Plate III, figs. 1 A, B.)

Platystrophia laticosta is characterized by the presence of 5 to 7 broad plications on each side of the fold. Both the fold and sinus are less compressed laterally than in *Platystrophia cypha*, and the lateral plications on the sides of the fold and sinus, though inconspicuous, are less commonly obsolete. The postero-lateral outline usually does not form angles more acute than 70 degrees. The shell is comparatively compressed antero-posteriorly. The typical specimens occur in the Fairmount bed, at Cincinnati, Ohio, and at corresponding horizons elsewhere, but similar forms occur also in the Bellevue bed at Madison, Indiana, Cincinnati, Ohio, Maysville, Kentucky, and also in the overlying Corryville. Specimens having the same general aspect occur also in the Waynesville bed, but usually the latter (plate III, figs. 3, 4) have narrower and more numerous lateral plications.

Several specimens of *Platystrophia*, plate III, figs. 2 A, B, received from Prof. Ray S. Bassler, and labelled as coming from the Waynesville bed at Waynesville, Ohio, can not be distinguished from many of the specimens of *Platystrophia laticosta* from the upper Fairmount, Bellevue, and lower Corryville horizons at Cincinnati, Ohio.

The later forms of *Platystrophia laticosta* are distinguished by the comparative distinctness of the lateral plications of the fold and sinus, which, although less conspicuous than the primary plications, are more distinct than in *Platystrophia cypha*.

It has been suggested that *Platystrophia acutilirata* was derived from *Platystrophia laticosta*, but some forms of *Platystrophia cypha* also appear available as a source of *Platystrophia acutilirata*.

Platystrophia crassa, James.

(Plate IV, figs. 5 A, B.)

In the *Cincinnati Quarterly Journal of Science*, vol. 1, p. 20, in 1874, U. P. James proposed the specific name *crassa* for the species illustrated in the *Ohio Geological Survey, Paleontology*, part 2, vol. 1, p. 117, plate 10, fig. 3, under the name *Platystrophia dentata*.

The first specimen figured, illustrated by figs. 3 a-c, has a hinge-line slightly longer than the width of the shell across the middle. Only two plications occur on the fold, and one in the sinus. The fold is prominent and narrow, and the sinus is correspondingly deep. The second specimen illustrated, fig. 3 d, has a somewhat different expression owing to the fact that the hinge-line is distinctly shorter than the width of the shell across the middle. The fold and sinus are similar to those of the first figured specimen, but a small additional plication occurs both in the sinus and on the fold. Neither of the specimens exceeds three-quarters of an inch in width. Meek, however, included also specimens an inch in width, and he gave the horizon as 250 to 300 feet above low water mark at Cincinnati, Ohio. This is the horizon from which Meek lists also *Strophomena planoconvexa*, *Dalmanella* *bellula, Cyclocoelia ella, Plectorthis plicatella,* and evidently is the Fairmount horizon.

James, in proposing the term *crassa,* includes specimens equalling an inch and a quarter in width, and gives the horizon as between 300 and 400 feet above low water in the Ohio river at Cincinnati. This would include the Corryville. The specimens from the Fairmount bed are here regarded as typical. It should be noted, however, that the specimens studied by Meek were sent to him by James and Shaffer of Cincinnati and evidently were selected specimens. There is no species in the Fairmount at Cincinnati which is characterized by the presence of only two plications on the fold and one on the sinus. By far the greater number of specimens have four plications on the fold and three in the sinus, but the two lateral plications on the fold are always less conspicuous and situated lower, on the sides of the fold. Frequently, these lateral plications are quite inconspicuous, are placed half way up the sides of the fold, and are matched by similar inconspicuous plications half way down the sides of the sinus. Specimens without any trace of the lateral plications (the typical forms of Meek) are very rare, and can be regarded as only aberrant forms of an otherwise abundant species. The hinge-line generally about equals the width of the shell across the middle, but may be slightly greater or less. The number of plications on each side of the fold usually is 5 or 6 but may equal 7. Specimens seven-eighths of an inch in width are not rare at the Fairmount horizon, but the average width is nearer three-quarters of an inch.

Platystrophia costata, Pander, is a much smaller species with a low fold and shallow sinus not strongly compressed laterally, and having an entirely different aspect viewed from the anterior side.

Platystrophia morrowensis, James.

(Plate VI, figs. 11 A,E; 12 A,B.)

In the James collection, in Walker Museum at Chicago University, there are several specimens labelled as the types of *Orthis morrowensis.* Only one of these was present at the time of original description of the species, and this is sufficiently characterized by its very short hinge-line, equalling about one-third of the greatest width of the shell. The general outline is oval, broader than long. The width is 9.7 mm.; the length, 7.7 mm.; and the thickness through the valves, 5 mm. The median fold is only moderately elevated, and is marked by four plications, two of which bifurcate anteriorly, but this is only an individual characteristic. As a rule, shells of this species have only four simple plications on the fold. Three plications occur in the sinus. The type (plate VI, figs. 11 A,E) is also abnormal in presenting an exceptionally short hinge-line.

Most specimens of *Platystrophia morrowensis*, as here interpreted, differ from the type of the species in having a distinctly longer hinge-line, frequently equalling four-fifths of the width of the shell. To specimens of this character, Ulrich gave the catalogue name, *Platystrophia similis*. Ulrich's specimens were secured 15 feet below the top of the Corryville bed, at Cincinnati, Ohio.

The very low, broad fold, and short hinge-line suggest young specimens of *Platystrophia ponderosa,* a much larger species occurring in the Mount Auburn bed, 15 feet higher. In *Platystrophia ponderosa,* however, the two primary plications on the fold are distinctly more conspicuous than the secondary plications within 7 mm. of the beak, and the two secondary plications are added at a distinctly lower level, at a distance of 3 or 4 mm. from the beak, while at this distance, those of *Platystrophia morrowensis* are already distinctly differentiated and lie very nearly at the same level. Moreover, all of the plications of *Platystrophia morrowensis* are sharper and more distinct than any specimens of *Platystrophia ponderosa* of the same size.

Platystrophia cypha, James.

(Plate IV, fig. 10 A,B; Plate V, fig. 11.)

The type specimen possessed the following characteristics: Shell elongated along the hinge-line into spine-like projections, being over two-thirds wider here than across the center of the shell, as is indicated by the following measurements. Width along the hinge-line, one and a half inches; width half way below the hinge-line, less than an inch; length, three-quarters of an inch. Shell extremely gibbous, the convexity equalling the width of the body below the spine-like projections. Brachial valve with a remarkably elevated median fold whose flanks form an angle of about 80 degrees with the sides of the shell. Pedicel valve with a profound sinus. Sinus with one strong elevated plication in the center and an obscure elementary one on each side. Fold with two strong plications on the crest, and although no obscure rudimentary plications are mentioned as occurring on the flanks, these must have been there in order to match those described in case of the sinus. Ten to twelve plications occur on each side of the fold. The anterior face of the shell, along the line of junction of the fold and sinus, is nearly flat or moderately convex. Compared with *Platystrophia crassa*, the shell is larger, more gibbous, has a more profound and longer sinus, a longer hinge-line, and more numerous plications.

Among the series of specimens preserved in the James collection in the Walker Museum of Chicago University as types of *Platystrophia cypha*, and numbered 2326, only one (plate iv, figs. 10 A,B, and plate v, fig. 11) is prolonged conspicuously along the hinge-line; it possessed twelve plications on each side of the fold. The spine-like projection on one side of the shell extends to about three-quarters of an inch from the beak. The spine-like prolongation at the opposite end of the hinge-line has been broken off. The other specimens can not be regarded as types since in these the prolongation of the shell along the hinge-line does not exceed an eighth of an inch and the number of plications on each side of the fold is 7 or 8 instead of 10 to 12. Although all of these specimens can not be regarded as the original types, they evidently all belong to the same species, if my interpretation of the limits of this species is correct.

The normal form of the species, to one extreme of which the name *Platystrophia cypha* has been applied, is characterized by the deep sinus and prominent fold, with one prominent plication in the sinus and two on the crest of the fold. There is a strong tendency toward the disappearance of the lateral plications of the sinus and fold, which is shown by their comparatively inconspicuous size and their situation half way down the flanks of the fold and the sides of the sinus. Occasionally, one of these lateral plications is entirely obsolete both in case of the sinus and the fold. Less frequently, both lateral plications are absent on the fold and also on the sides of the sinus. The number of lateral plications on each side of the shell usually varies from 6 to 8, and increases to 10 and 12 as a rule only in case of shells which are conspicuously prolonged along the hinge-line.

Shells conspicuously prolonged along the hinge-line and with 10 to 12 plications on each side of the fold were selected by James as the type of his species, *Platystrophia cypha*.

Shells belonging to the opposite extremity of the series, with the postero-lateral angles almost rectangular, with only 5 or 6 lateral plications, and with the lateral plications on the fold and on the walls of the sinus almost or entirely obsolete, form the *Platystrophia unicostata* of Cumings. (Plate IV, fig. 6.)

Between these extremes belongs the larger series with only a moderate extension along the hinge-line, with 6 to 8 lateral plications on each side of the fold, and with the lateral plications of the fold and sinus more frequently present, though inconspicuous.

All the variants of *Platystrophia cypha* have been found in the upper part of the rich *Platystrophia ponderosa* beds at the Bellevue horizon, and in the overlying Corryville beds at Madison, Mount Sterling (plate IV, fig. 12 A,B), Vevay, and New Hope church in Ohio county, in Indiana. This may have been the horizon also at which James collected his type specimens in Warren county, Ohio.

Cumings has pointed out the probable derivation of *Platystrophia unicostata* from *Platystrophia laticosta* of the Fairmount bed. The later developments of *Platystrophia cypha* also are of interest.

If emphasis be laid on the prominence of the fold, the depth of the sinus, the tendency toward prolongation along the hinge-line, and the inconspicuous size and low position of the lateral plications of the fold rather than their absence, then the descendants of *Platystrophia cypha* can be recognized readily in the Arnheim. For instance, one mile south of Mount Washington, and a mile south of Smithville, on the road from Louisville to Bardstown; near Lebanon; three miles south of Maysville, Kentucky (plate iii, fig. 5). Also three miles northeast of Goshen in Clermont county, and at Oregonia in Warren county. At the locality one mile south of Mount Washington, Kentucky, specimens with spine-like prolongations along the hinge-line were found which agree with James's original description better than does the best of his series of type specimens.

A somewhat similar group of specimens occurs in the Waynesville bed. In this group, the lateral plications on the fold sometimes are inconspicuous and situated low on the flanks, but more frequently they are farther up the sides of the flanks and tend to be more conspicuous than in the case of shells from lower horizons. Shells of this type occur in the Waynesville at Madison, and Versailles, Indiana, at Oregonia, and Clarksville, Ohio, and at Concord, Kentucky. They range as high as the upper or Blanchester division of the Waynesville bed at Moores Hill, Indiana (plate iv, fig. 13 A,B), and at Woodville, in Clermont county, Ohio.

Possibly *Platystrophia acutilirata* was derived from the *Platystrophia cypha* stock. In that case the process of evolution demands a reduction in the height of the fold and an increase of the size and elevation of the lateral plications of the fold; in other words, a reversal in part to former conditions. The tendency toward prolongation along the hinge-line and toward a larger number of lateral plications on each side of the fold than in *Platystrophia laticosta* remains. The possibility of the derivation of *Platystrophia acutilirata* in a more direct line from *Platystrophia laticosta* must be considered elsewhere.

The typical characteristics of *Platystrophia cypha* are the high median fold of the brachial valve, the deep sinus of the pedicel valve, with a tendency toward the disappearance of the two exterior plications from the group of four plications occupying the fold, and from the group of three plications occupying the sinus. While the shell is prolonged into a spine-like projection along the hinge in the type specimen, this is an extreme form of the species. In the Arnheim bed, half a mile south of Smithville, in Bullitt county, Kentucky, and at corresponding horizons elsewhere in Kentucky, west of the Cincinnati geanticline, a form of *Platystrophia* occurs (plate iv, figs. 7 A,B, and 14 A,B.) which may represent a line of development from *Platystrophia cypha* toward *Platystrophia acutilirata*. In these specimens the sides of the shell, on each side of the fold and sinus, on ventral view, appear compressed instead of inflated as in typical *Platystrophia cypha*. However, some of the specimens show a fairly conspicuous fold and sinus, and there is a tendency toward the disappearance of the exterior pair of plications of the fold and sinus (figs. 7 A,B), while in other specimens the elevation of the fold and the depth of the sinus are distinctly less, the exterior plications of the fold and sinus are more conspicuous, (figs. 14 A,B) and this type of shell may have led to *Platystrophia acutilirata*. There is a considerable variation in the number of lateral plications, but these tend to be numerous in the broader shells. For shells of this type the name *Platystrophia cypha-conradi* is proposed.

Platystrophia cypha-conradi appears to have been a precursor of the type of shell which is very prolonged along the hinge-line, is of only moderate length, and which shows a tendency toward the disappearance of the exterior plications of the fold and sinus. Shells of this type(plate iv, figs. 11 A, B) occur in the Liberty bed at Versailles, Indiana, and for these the name *Platystrophia cypha-versaillesensis* is suggested. Similar specimens occur in the Blanchester division of the Waynesville bed along the road from Moores Hill to Holman, north of Hogan creek (plate iv, figs. 13 A,B).

Platystrophia acuminata, James, from the Mount Auburn or lower Arnheim at Cincinnati, Ohio, judging from its relatively great width and acute postero-lateral angles, belongs to the *Platystrophia cypha* group of shells, and may be merely a young specimen of one of those forms in which the lateral plications on the fold and in the sinus are better developed. The type (plate vi, figs. 13 A,B) numbered 1562, is preserved in the James collection in the Walker Museum, at Chicago University.

Platystrophia clarksvillensis, sp. nov.

(Plate III, figs. 4,3.)

In the Clarksville division of the Waynesville bed there is a form of *Platystrophia* which bears some resemblance to *Platystrophia laticosta.* (Fig. 4.) It differs chiefly in having narrower, more numerous plications, the number of lateral plications being 7 to 9; the four plications occupying the fold are more nearly of the same size, resulting in a relatively broader and less angular fold and sinus. These specimens closely resemble *Platystrophia acutilirata* but differ in having a less obese convexity when seen from the anterior side. The specimens possibly may be in the line of development from *Platystrophia laticosta* toward *Platystrophia acutilirata.* They are especially common in the Clarksville division of the Waynesville bed, but they begin in the Fort Ancient division, are found in the Blanchester division, and continue into the Liberty bed. Typical forms of *Platystrophia acutilirata* occur in the Whitewater bed.

Platystrophia acutilirata, Conrad.

(Plate III, figs. 6, 7, 8 A, B.)

Conrad described *Platystrophia acutilirata* as coming from the Silurian shale at the Falls of the Ohio river, Kentucky. Since his species unquestionably is from some horizon in the Richmond group, and since no part of the Richmond is exposed in the immediate vicinity of Louisville, it is evident that his type must have been obtained from some other locality.

It is customary to identify as *Platystrophia acutilirata* the Whitewater form which is so abundantly exposed at Richmond, Indiana, and at corresponding horizons in Ohio and Indiana. This view is favored by the ventricose appearance of the body of the shell, mentioned in the original description and indicated in the accompanying figure; also by the acute hinge extremity and by the relatively considerable number of lateral plications. In the original description 32 lateral plications are mentioned which would result in 16 plications on each side of the fold. In the accompanying figure, 12 plications are represented on one side and 14 on the other side of the fold.

As a matter of fact, however, the Whitewater bed does not appear to be exposed nearer than Versailles, Indiana, and the Liberty representatives of this type of *Platystrophia* rarely have more than 11 lateral plications on each side of the fold, although such specimens do occur occasionally, but even then the number does not equal 14 or 16. The Liberty bed, however, is abundantly exposed at numerous localities within 30 miles of Louisville, and is richly fossiliferous.

Specimens with numerous lateral plications occur also at numerous localities in the Arnheim bed west of the Cincinnati geanticline between the Ohio river and Lebanon, Kentucky. One of these localities, south of Salt river on the road from Louisville to Bardstown, was along one of the chief lines of travel at the time Conrad wrote his description. The specimens of *Platystrophia* found here (plate iv, figs. 7 A,B, 14 A,B) are characterized by the prominence of the fold, the depth of the sinus, the sharpness of the plications, the acute lateral extremities, and by the antero-lateral compression of these extremities which gives them a wing-like rather than spine-like appearance. The number of lateral plications on each side of the fold frequently is 11, and sometimes equals 14. Similar shells, found in the Arnheim along the same line of travel, one mile south of Mount Washington, are more ventricose, and occasionally have more spine-like projections of the shell along the hinge-line, and numerous lateral plications, but only in case of selected specimens.

In general outline, in the ventricose appearance of the body of the shell, and in the number of plications, however, Conrad's figure resembles the common Whitewater form from the vicinity of Richmond, Indiana, and from corresponding horizons in Ohio and elsewhere in Indiana, rather than the Liberty or Arnheim forms seen within a reasonable radius of Louisville, Kentucky. His type specimen evidently was mislabelled as far as the locality was concerned. Conrad described other species from Richmond, Indiana. This identification of *Platystrophia acutilirata* with the Whitewater form is in common use, and nothing can be gained by seeking some Kentucky source for the origin of Conrad's type, especially in view of the absence of the type specimen itself.

As in the case of *Platystrophia cypha,* there is every variation between specimens in which the length of the hinge-line does not exceed the width of the shell across the middle, or even is a little less, and those in which the shell is prolonged into spine-like projections along the hinge-line.

The first mentioned extreme forms the variety *inflata* of James. Specimens of this type (plate iv, fig. 8 A,B) are strongly gibbous. The hinge-line about equals the width of the shell, and the latter is not more than one-fifth greater than the length in specimens which are considered most typical of this variety. One of the type specimens preserved in the James collection in the Walker Museum of Chicago University, belonging to a series labelled *Platystrophia inflata* and numbered 1561, has the following dimensions: length, 17.5 mm.; width across the middle of the shell, 23 mm.; length of the hinge-line, 23.5 mm.; gibbosity of the shell, 21 mm. The characteristic low, broad, rounded fold and shallow sinus of *Platystrophia acutilirata* are present.

The other extreme (plate iii, figs. 8 A,B), called *Platystrophia prolongata* by James, consists of shells distinctly prolonged along the hinge-line into spine-like projections. Frequently these projections are merely distinctly acute, with a slightly concave outline on the lateral side of the shell, and scarcely can be called spine-like. Specimens of the latter type form the typical *Platystrophia acutilirata* of Conrad, as here identified and as figured by Meek in the *Ohio Paleontology,* vol. 1, plate x, fig. 5a.

Platystrophia acutilirata-senex, the serontic characteristics of which are so admirably described by Cumings, includes two forms. The one first figured (*Indiana Geol. Survey,* 32nd Report, 1908, plate 35, fig. 4) corresponds essentially to typical *Platystrophia acutilirata* of Conrad and Meek. Figures 4 a-c on the same plate correspond to the variety *inflata* of James.

Platystrophia annieana, James, consists of shells evidently belonging to the typical *Platystrophia acutilirata* group, but differing in having the lateral margins convex rather than concave. The tendency toward a spine-like prolongation of the shell along the hinge-line, in other words, is missing. Viewed directly from in front, these shells appear more evenly convex, and less ventricose centrally. The number of lateral plications varies from 12 to 16 on each side of the fold. Specimens of this type occur at various horizons, but only as selected specimens, and not in sufficient numbers to suggest more than individual characteristics. James's types (No. 84, James Collection, Walker Museum, Chicago University) were secured in the upper part of the Waynesville bed, at Blanchester, Ohio. (Plate vi, figs. 14 A-C.)

Typical *Platystrophia acutilirata* is characterized by the low, broad, rounded fold, with four plications of approximately equal size, a strongly ventricose shell, and rather numerous lateral plications on each side of the fold. Shells of this type, with all the variations, from *Platystrophia inflata* to *Platystrophia prolongata,* occur everywhere in the Whitewater bed, in Indiana and Ohio. The specimens from the upper part of the Whitewater bed at Richmond, Indiana, and Dayton, Ohio, are especially typical.

Specimens belonging to the *Platystrophia inflata* group, but with the width distinctly greater than the length, and the number of lateral plications often as low as 7 to 9 on each side of the fold, are common in the representatives of the Whitewater bed in Ripley, Jennings, and Decatur counties, Indiana.

Forms similar to *Platystrophia inflata* occur in the Liberty bed, on the west side of the Cincinnati geanticline, as far south as Raywick, Kentucky. They are associated at Cane Springs, Bardstown, and elsewhere, with forms having the lateral outline of typical *acutilirata,* but all of these Liberty forms are distinctly less ventricose than those from the Whitewater bed near Richmond, and there is a tendency toward fewer lateral plications on each side of the fold. The fold frequently is more elevated, especially along the middle.

Two distinct types of shells occur in the Waynesville bed. In one of these, the fold is prominent, and the lateral plications on the fold are distinctly less conspicuous and placed lower. Shells of this type appear to grade into *Platystrophia cypha.* Both shells with acute postero-lateral outlines, as in case of *Platystrophia acutilirata,* and shells with rectangular postero-lateral outlines are present, for instance at Madison, Versailles, and Bull creek, Indiana.

In the other type of shell found in the Waynesville bed (plate iii, figs. 3, 4), the fold is lower, the plications on the fold are more nearly of equal size, the shell is broader than in *Platystrophia inflata,* but the postero-lateral outline is approximately rectangular or but moderately acute. Specimens of this type grade into a form with relatively few plications, and somewhat resembling *Platystrophia laticosta.* Specimens of this type occur at Concord, Kentucky; Fort Ancient, Oregonia, and Waynesville, Ohio; and at Versailles and Madison, Indiana. Some of the specimens at Concord, Kentucky, resemble *Platystrophia inflata* in outline.

With numerous specimens from all horizons and from widely separated localities in Ohio, Indiana, and Kentucky at hand, it has been found impossible to determine the exact line of derivation of *Platystrophia acutilirata.* Much remains to be done. Future work will require a study of *Platystrophia* by faunal associations, its range of variation within those associations, and the spread of these variations along with the general associated faunas, geographically as well as vertically. The collection of prodigious quantities of specimens from some large vertical section is a valuable factor in such a problem, but in itself is insufficient to solve the complicated problem involved. Owing to the enormous amount of material which could be readily collected, the line of development of the various forms of *Platystrophia* will remain an interesting problem for a long time. The admirable studies by Prof. E. R. Cumings are classic. The notes here presented are merely an attempt to call attention to some of the species and varieties present in the area of the Cincinnati geanticline in such a manner as to give a little more definiteness to some of the names commonly used or almost forgotten.

Clitambonites rogersensis, Foerste.

A comparison of *Clitambonites rogersensis* from the Rogers Gap division of the Economy bed, at Rogers Gap, Kentucky, with typical specimens of *Clitambonites diversus,* Shaler, has shown that the Kentuckian form is more distinct than at first supposed. The interior of the shell of *Clitambonites diversus* is covered by coarse intertwining vascular markings, which in *Clitambonites rogersensis* are comparatively inconspicuous. The shell of *Clitambonites rogersensis* is broader and shorter. The pedicel valve, in consequence, appears less convex, and the beak appears less conspicuously elevated. The brachial valve is transversely elongate, while that of *Clitambonites diversus* is subquadrate in outline. The anterior outline of *Clitambonites rogersensis* not infrequently is slightly reentrant or concave, but this is not a constant feature.

Opisthoptera concordensis, sp. nov.

(Plate I, fig. 9.)

Along the creek east of Concord, Kentucky, the *Strophomena concordensis* zone is almost at the base of the actually exposed section, a short distance south of the railroad bridge. Five and a half feet lower, the lowest specimens of *Streptelasma vagans* were found, associated with a species of *Opisthoptera*. Five feet higher, *Streptelasma vagans* and *Columnaria alveolata* occur. Seven and a half feet above the *Strophomena concordensis* layer, the species of *Opisthoptera* occurs again, associated with the lowest specimens of *Dalmanella jugosa* found at this locality. A specimen of *Opisthoptera* collected from the higher horizon just mentioned possesses the following characteristics:

Greatest length of the left valve, from the beak to the ventral border, 75 mm. Greatest convexity of this valve, 15 mm. Byssal opening well defined. About 20 primary plications reach the beak. Along the more elevated part of the valve, within 40 mm. from the beak, these primary plications are dichotomously divided into two. Anteriorly and posteriorly this division takes place nearer the beak. Along the ventral third of the main body of the shell, an additional plication occupies the depression between the pairs of more prominent plications resulting from this dichtomous division. Posteriorly, the intercalated plications have about the same prominence as the pairs resulting from the division; in consequence, the shell appears here more closely and evenly plicated. Anteriorly, the posterior division of the primary plication appears more prominent.

This species appears closely related to *Opisthoptera alternata*, Ulrich. It is distinguished by the paired appearance of the dichotomously divided primary plications over the larger part of the body of the shell.

Pterinea (Caritodens) demissa, Conrad.

(Plate I, fig. 10.)

Pterinea demissa, Conrad, as identified from the Cincinnatian strata of Ohio, Indiana, and Kentucky, differs from *Pterinea laevis,* the type of the genus, in the absence of a well defined, longitudinally striated ligamental area. Along the hinge line, a narrow linear portion is bent parallel to the general plane of the valves, and then inward along the margin, serving as an area of attachment of the valves but without any ligamental thickening or striation. No anterior cardinal teeth have been seen. The anterior muscular scar must be faint, since it has escaped detection so far. Agreeing with *Pterinea* are the greater convexity of the left valve, the low convexity of the right valve, becoming flat or slightly concave ventrally in mature shells, the well developed ear and wing, and the obliquity of the body. The posterior muscular scar is large, but not sharply impressed.

In the Whitewater bed, west of Camden, Ohio, the cast of both valves is marked along the line of junction between the body and the wing by a deep groove, 12 mm. in length in specimens 55 mm. high. These grooves indicate the presence of a single prominent linear posterior tooth in each valve. A similar specimen was found in the Hitz layer, at the top of the Saluda bed, at Madison, Indiana. Careful search among the numerous specimens of *Pterinea demissa* in the Arnheim and Waynesville beds has failed to reveal similar posterior teeth on well exposed interiors, nor have any been found in specimens from the Maysville formation. Possibly the Whitewater forms here described belong to a different species.

Pterinea demissa appears to be a distinctly more primitive type than *Pterinea laevis.* This is true especially of the Maysville and lower Richmond forms in which the posterior lateral teeth appear to be absent. These earlier forms are here chosen as the type of the more primitive group for which the term *Caritodens* is proposed.

A valve from the Arnheim bed at Clifton, Tennessee (Plate I, fig. 10) is identified with *Pterinea demissa.*

Conocardium richmondensis, sp. nov.

(Plate II, figs. 21 A,B.)

Shell sub-trigonal; hinge-line straight; beaks apparently anchylosed and forming a transverse ridge which is extended into the umbonal ridge separating the anterior truncated face from the posterior part of the shell. This umbonal ridge is formed by the most prominent plication on the shell. It is angular, the anterior face of the shell being deflected almost at right angles to the posterior body. The anterior face extends as an obtusely angular cone about one millimeter beyond the umbonal plane, and then is produced as a laterally flattened acute extension along the hinge-line for an additional distance of at least two millimeters, the extreme tip not being preserved in the specimen at hand. Viewed from in front, this extension appears like a vertical lamella, extending downward into the sharp angle formed by the junction of the anterior margin of the valves. Anterior to the acutely angular umbonal ridge is a low, broad plication, about one millimeter from the umbonal ridge at the ventral margin. Anteriorly, this plication is distinctly limited by a strong groove extending as far as the beak; posteriorly this plication is limited by another groove, distinct only along the ventral half of the shell. Four or five practically obsolete plications intervene between the prominent one just described and the anterior extension of the shell. Posterior to the umbonal ridge, the umbonal region is marked by two distinct plications, the first of which is about one millimeter from the umbonal ridge, and the second is about a third of a millimeter from the second. Deep grooves intervene between the plications of this umbonal region, the anterior groove being broad and conspicuous. Posterior to the second plication from the umbonal ridge, the shell is constricted distinctly, and this posterior region is marked by distinct but narrow plications, of which twelve or thirteen reach the hinge-line in the specimen at hand. Several additional striae are intercalated anteriorly, and the posterior border is imperfectly preserved. Conspicuous striae, parallel to the ventral margin of the shell, cross the posterior region of the shell, and produce a net-work with approximately quadrate meshes. In the umbonal region these striae appear to be almost obsolete. The anterior face of the shell is marked by a net-work of extremely fine striae, part parallel to the plications already described, and part parallel to the ventral margin of this part of the shell. These striae are visible only under a strong light carefully directed, when examined by a strong lens. The umbonal ridge makes an angle of about 115° with the hinge-line. The distance from the beaks to the ventral margin of the shell at the umbonal ridge is 5.5 mm. The distance of the beak from the posterior end of the shell, as far as preserved, is 3.5 mm. The distance from this posterior end of the shell to the ventral margin at the umbonal ridge is about 6.3 mm. The ventral margin makes an angle of about 35° with the hinge-line.

Since only a single specimen of this species is known, it may be necessary to modify this description eventually, but the specimen is sufficiently distinct from all others hitherto described to make its chief characteristics apparent.

Conocardium richmondensis was found 15 feet below the Clinton or Brassfield limestone, on Elkhorn creek, three miles south of Richmond, Indiana, associated with *Beatricea undulata, Streptelasma vagans, Columnaria alveolata, Columnaria vacua, Hebertella sinuata, Platystrophia acutilirata, Platystrophia moritura, Schizolopha tropidophora, Helicotoma marginata,* and *Ischyrodonta ovalis.* The conspicuous *Ischyrodonta* layer occurs immediately above.

Conocardium immaturum, Billings, from the Black River limestone at Paquette Rapids, on the Ottawa river, has a much broader umbonal region marked by numerous radiating striae.

Clidophorus, sp.

(Plate I, figs. 8 A, B.)

A species of *Clidophorus* occurs in the Saltillo bed, at Clifton, Tennessee, which closely resembles *Clidophorus neglectus,* Hall, from the Maquoketa shales of the upper Mississippi basin, but the umbonal ridge is less angular, the posterior outline is more rounded, and the clavicle, instead of sloping backward, slopes forward, leaving a shorter anterior muscle scar. It probably is a new species, but difficult to differentiate from some of those already defined.

Suecoceras inaequabile, Miller.

(Plate I, figs. 1, 2.)

Endoceras inaequabile was described by S. A. Miller from the Richmond group at Bristol, Illinois. It consists of the lower end of the siphuncle, showing the impressions of the septal necks as far as the tip, indicating that the nepionic bulb had been completely incorporated into the phragmocone. These impressions are inclined away from the apical end and toward the straight side of the nepionic part of the siphuncle.

A similar specimen was found at Clarksville, Ohio, in the

Orthoceras fosteri bed, at the base of the Middle or Clarksville division of the Waynesville bed. The specimen had been crushed laterally toward the apical end. The distance between the septal impressions is 7 or 8 mm. At and beyond a distance of 75 mm. from the apical end, these impressions are distinct. Nearer the apical end, these impressions are represented chiefly by equally distant transverse, oblique wrinkles.

A much smaller, but otherwise similar specimen was found in the Richmond group at Madison, Indiana, presumably in the Waynesville member.

The similarity to *Succoceras* appears confined to the exterior appearance of the nepionic bulb. No structure can be detected within this bulb. The upper end of the specimen from Clarksville is covered on one side by a thin encrusting expansion of some bryozoan, indicating that the remainder of the shell had been removed before the siphuncle had become imbedded in the mud at the bottom of the sea. The walls of the siphuncle are very thin, and those of the remainder of the shell must have been very fragile or easily dissolved. These siphuncles probably belong to a new genus, as yet too imperfectly known to admit of characterization.

Cyrtocerina madisonensis, Miller.

Cyrtocerina madisonensis is found in considerable numbers in the Hitz layer, at Madison, Indiana, but has not been noticed elsewhere so far.

Orthoceras (Dawsonoceras) hammelli, sp. nov.

(Plate I, fig. 4.)

At the top of the Saluda bed at the Dog Falls, on Saluda creek, in Jefferson county, Indiana, an annulated species of *Orthoceras* occurs in which the annulations, from one point of view, are moderately inclined. One fragment, 53 mm. in length, with 15 annulations, has a width of 19.5 mm. at the top and 17.3 mm. at the base. The annulations are broad and low, and their elevation above the intermediate grooves is scarcely half a millimeter. About 5, sometimes 4 or 6, distinct longitudinal striae occupy a width of 5 mm. near the top. Between each pair is a less distinct striation, and usually two additional striations readily visible only under a lens. In addition to the annulations there are transverse striations, visible only under a lens. About four septa occupy a length equal to the width of the shell.

Orthoceras hammelli occurs at the Wallace Horrell locality, 5 miles south of Hanover. Smaller fragments of the same species occur in the Hitz layer, at the top of the Saluda bed, at Madison, Indiana; and two miles east of Tucker, in Jefferson county, Kentucky, at the overhead bridge, crossing the Southern Railroad. In these specimens the primary longitudinal striations are conspicuously stronger than the intermediate ones.

Specimens of *Orthoceras hammelli* of about the same size as the type specimen occur at numerous localities in the "mottled" limestone, forming the upper part of the Saluda section in many parts of southeastern Indiana. It occurs at this horizon at the railroad cut west of Weisburg, 16 feet above the "shale bed," associated with *Entomis madisonensis, Eurychilina striatomarginata, Leperditia caecigena, Primitia cincinnatiensis,* and *Primitia milleri.* At the creek, east of Ballstown, in Ripley county, Indiana, *Orthoceras hammelli* occurs within 5 feet above the massive *Tetradium* layer, at the base of the Saluda bed. A mile and a half northeast of Enochsburg, in Franklin county, a specimen was found loose at the Saluda horizon, 15 feet above Big Salt creek.

A large specimen, 36 mm. in diameter, was found in the Elkhorn bed, at West Milton, Ohio. In this specimen the primary longitudinal striations occur at intervals of about 3 mm. The median secondary striations are inconspicuous, and the intermediate striations can be seen only under a lens.

Compared with *Orthoceras gorbyi,* Miller, the septa are more remote, and the annulations are either directly transverse or only moderately oblique. Compared with *Orthoceras perroti,* the annulations are much less prominent, and the longitudinal striae are never very conspicuous or developed into lamellar expansions.

Orthoceras (Spyroceras) bilineatum-frankfortensis, sp. nov.

(Plate I, figs. 6 A, B.)

South of Glenn creek, at the Crow distillery, 6 miles southeast of Frankfort, Kentucky, the Logana bed, with *Heterorthis clytie,* is well exposed. The underlying cherty limestone, containing *Orthis tricenaria,* is referred by Prof. Arthur M. Miller to the Curdsville bed. This cherty limestone contains a species of *Orthoceras* characterized by low, transverse annulations, rising scarcely half a millimeter above the flat, intermediate grooves. There are 7 annulations in a length of 22 mm. in a specimen about 22 mm. wide. The annulations are crossed by sharp, longitudinal striae, about 10 or 11 in a width of 5 mm. Between these more prominent striae, single, very fine striae may be seen with a lens. These longitudinal striae are crossed by very much finer but very distinct transverse striae, about 11 in a length of one millimeter.

In *Orthoceras bilineatum,* the longitudinal striae appear to be much more distant. In *Orthoceras clathratum,* the intermediate striae are absent, although the very fine transverse striae are distinct.

Orthoceras (Loxoceras) milleri, sp. nov.

(Plate I, fig. 5; Plate II, figs. 24 A, B.)

Orthoceracone with circular section, and having a small rate of growth, about 7 mm. in a length of 80 mm. in the larger specimen at hand. This specimen, 80 mm. long, has a width of 38 mm. at the top and 31 mm. at the base. The cameras are shallow, 5 occupying a length of 15 mm. near the smaller end of this specimen. The concavity of the septa equals the depth of two and a half cameras. The siphuncle is strongly nummuloidal. At the larger end of the specimen its width at the septum is 7 mm., at the smaller end its width is 6 mm. Within the cameras the width enlarges considerably, equalling 9 mm. at the smaller end. The inner walls of the nummuloidal segments of the siphuncle are lined with a heavy deposit of calcareous material, leaving a narrow central opening at the septa, but there is no evidence of a radiate structure, as in *Actinoceras.* Similar calcareous deposits line the interior of the cameras. The exterior of the casts of these cameras is marked on one side by faint longitudinal lines, of which there are no trace on the exterior surface of the small fragments of the thin test of the phragmocone remaining locally attached to the casts of the interiors of the cameras.

Several specimens of this species were found in the Perryville bed, about 2 miles south of the Crow distillery, east of the road, near the home of Allen McGarvey, on the farm owned by Mrs. Ben Williams. The locality is one mile southeast of McKee ferry, in Woodford county, Kentucky, about 7 miles south of Frankfort. I desire to name this species in honor of Prof. Arthur M. Miller, of Kentucky State University, who has given much attention to the Ordovician rocks of Kentucky, and to whom I am much indebted for information regarding the same.

Orthoceras (Ormoceras?) hitzi, sp. nov.

(Plate I, fig. 3; Plate II, fig. 22.)

Surface smooth when unweathered; in weathered specimens, longitudinal, flat, raised lines make their appearance. These seem to be due to differences in the resisting powers of different parts of the shell to weathering, or to the internal structure, rather than to raised lines marking the inner surface of the shell cone. In some specimens, these striae have a width of one-third of a millimeter. In others, their width is less. The number of longitudinal striations varies usually between 6 and 9 in a width of 5 mm., but greater numbers are found in some specimens. Orthoceracone rather small, gradually tapering. In a specimen 41 mm. long and 15 mm. wide at the larger end, the width at the smaller end is 9.5 mm. In this length there were 19 septa, of medium concavity. The siphuncle is strongly annulated. The bead-like segments equal in width about forty-three hundredths of the width of the shell at its smaller end; at the constrictions where passing through the septa the width of the siphuncle is about half as great. The cross-section of the shell is circular, and the siphuncle is more or less excentric. The septa, as a rule, are symmetrically transverse, but occasionally are oblique to the length of the shell, possibly due to some physical defect of the individual animal. While the siphuncle is constricted in passing through the septa, a thin lamella, having about the same curvature as the septa, appears to cross the bead-like expansions about half way between the septa, and at this elevation, in the upper part of the shell, the casts of the interior of the bead-like expansions appears constricted in a manner somewhat suggestive of *Ormoceras.*

Compared with *Orthoceras mohri,* Miller, and *Orthoceras fosteri,* Miller, the bead-like expansions of the siphuncle are much wider. Compared with *Orthoceras hallanum,* Miller, the bead-like expansions are relatively wider and occupy a much greater part of the width of the shell. Nothing is known of *Orthoceras carleyi,* Hall and Whitfield, beyond the fact that the tube enlarges slowly, there are about 6 or 7 septa within a length equal to the width of the shell, and the specimen was found at Fayetteville, in Brown county, Ohio, probably in the Waynesville bed.

Compared with *Ormoceras crebriseptum,* the exterior surface of the shell appears smooth.

Orthoceras hitzi occurs in the Hitz layer in southern Indiana and northern Kentucky, west of the Cincinnati geanticline. The type specimens were found at Madison, Indiana. It has been found also on Camp creek in Clark county; at the Dog Falls on Saluda creek, on the road from Hanover to the Landing, on the Hitz road and on the Hanging Rock road at Madison, at the falls on Crooked creek, one mile northeast of Madison on the road to Riker's ridge, at the falls on Razor creek, along the road a mile and a half southeast of Belleview, a mile north of Belleview, two miles south of Poplar ridge, all in Jefferson county, Indiana. Also four miles west of Cross Plains; and one mile west of Ballstown, in the "mottled" limestone, 13 feet above the top of the Bosberg quarry and about 20 feet above the "shale bed," in Ripley county, Indiana. In the mottled limestone, 16 feet above the shale bed, at the railroad cut west of Weisburg, in Dearborn county, Indiana. It occurs at numerous localities between the locality along the railroad two miles east of Tucker, in Jefferson county, and the area east of Pewee Valley, east of Floyds creek, in Oldham county, Kentucky.

Cyrtoceras hitzi, sp. nov.

(Plate I, figs. 7 A, B; Plate II, figs. 23 A,B,C.)

In the Hitz layer at Madison, Indiana, a very small species of *Cyrtoceras* occurs which is characterized by prominent, transverse striae, which are deflected along the ventral line like a letter V, rounded at the base. Laterally, these striae are directly transverse and approximately straight, or at least not conspicuously wrinkled. At the small end of the fragment, 3.3 mm. in diameter, the transverse section is almost circular. At the larger end, 8 mm. in width, the lateral diameter may exceed the dorso-ventral but the dorsal side is not preserved. Along its length of 17 mm. there are 30 transverse striae. At the larger end, there are 7 in a length of 5 mm. The curvature of the shell is moderate, less than 2 mm. on the ventral side of the specimen at hand. The number of septa is approximately the same as that of the transverse striae. The sipho is unknown.

The small curvature of the shell, the sharp transverse striae deflected backward along the ventral line, and the comparative strightness of these striae laterally are the distinguishing characteristics of *Cyrtoceras hitzi*.

Cryptolithus tessellatus, Green

The lowest horizon at which the species long familiarly known as *Trinucleus concentricus* occurs is the Logana limestone, at Frankfort, Kentucky. *Trinucleus* is not known from the Wilmore and Paris divisions of the Lexington formation, nor from the lower, Greendale division of the Cynthiana formation. At West Covington, Kentucky, *Trinucleus concentricus* occurs as low as 20 feet below the *Triarthrus becki* horizon. At New Richmond, Ohio, it occurs 11 feet below this horizon. At Point Pleasant, it occurs 11 feet below the *Triarthrus horizon*, and also 35 feet below this horizon. Mature specimens occur at the *Triarthrus becki* horizon, and also in the overlying parts of the Fulton layer, at Point Pleasant, Ohio, at Ivor, Kentucky, and elsewhere along the Ohio and lower Licking rivers. From this level, it ranges through the Economy member and as far as the middle of the Southgate member of the Eden formation, in Ohio, Indiana, and northern Kentucky. It it abundant in the Eden west of Falmouth, Kentucky. A few specimens, associated with *Leptaena gibbosa*, occur in the lower Eden north of Boyd. A short distance northeast of the railroad station, at Ford, *Trinucleus* occurs in an argillaceous limestone, associated with *Ceratopsis intermedia*. It occurs frequently in the Rogers Gap bed, in the lower Eden, between Sadieville and Rogers Gap. At Sparta, it is common above the railroad level, in strata associated with *Prasopora contigua, Eridotrypa mutabilis, Eridotrypa briareus, Ceratopsis intermedia, Primitia bivertex,* and other fossils indicating a horizon beneath the typical Eden. It occurs in the lower Eden east of Hatton, west of Lawrenceburg, and at the top of the new branch of the Southern railroad, a short distance beyond the junction a mile and a half southeast of Harrodsburg. While the exact stratigraphy of most of these localities has not been determined as yet, it is known that the vertical range of *Trinucleus concentricus* diminishes rapidly southwards, amounting to only a few feet at the more southern localities. This may be due in part to a thinning of some of the lower Cincinnatian strata southwards.

An article entitled *Synopsis of the Trilobites of North America* was published by Dr. Jacob Green in the *Monthly American Journal of Geology and Natural Science*, volume 1, No. 12, at Philadelphia, in 1832. This number should have appeared in June, and it is so dated, but the publisher having become bankrupt, the editor was forced to publish the last number at his own expense. Since a letter from Blountsville, Tennessee, dated August 3, 1832, is noted on page 565, and travel at that time was slow, it is scarcely likely that the number as a whole appeared before the close of September of that year. The article on North American trilobites begins on page 558. A break occurs at the close of this article ,on page 560, and it would have been possible to distribute the earlier pages of this number, evidently printed before the trouble with the publisher became serious (page 566), without awaiting the completion of the number, but there is no evidence that this was done.

Cryptolithus tessellatus, Green, published on page 560, evidently is the same species as *Trinucleus concentricus*, and of this there never has been any doubt. The generic characteristics, considering the date of publication, are clearly indicated. The genus and species were founded upon a specimen collected by Hall from the slates of the Lorraine beds at Waterford, New York, and still in the possession of Hall at the time of publication of volume 1, *New York Paleontology*.

The same specimen was used by Prof. Amos Eaton in describing *Nuttainia concentrica*, although in this description the Trenton locality at Glennsfalls is mentioned first. The description appears on page 33 of the second edition of Eaton's *Geological Text book*, dated June 15, 1832. Unfortunately, the date of a preface is no indication of time of publication of a book, beyond the fact that the latter usually is later. There is no doubt that Green's *Monograph of North American Trilobites*, dated October 1, 1832, appeared later than Eaton's Geological Text book, but on page 88 of his *Monograph* Green states the genus *Cryptolithus* was proposed before the appearance of Eaton's work, evidently in his *Synopsis*, published in the *Monthly American Journal*. That this is possible is shown by the fact that some geological libraries contain copies of the *Monthly American Journal of Geology and Natural Science* which terminate with the close of Green's Monograph, and do not contain the following pages. One of these copies is in the Library of the Walker Museum, at Chicago University, one of the very rare complete copies also being present.

There is no question that the genus *Nuttainia* was founded upon the species usually called *Trinucleus concentricus*, and there is no confusion in the generic description, as the following quotation from Eaton's text-book will show:

> *Nuttainia.* Head in three lobes, the middle one most prominent; the two lateral lobes, sub-hemispherical or sub-quadrantal: the whole head bordered anteriorly with a punctured fillet; body distinctly three lobed, middle lobe subcylindric, and not so broad as the side lobes.

I am unable to see why the fact that Eaton incorrectly referred a glabellar fragment of *Homolanotus dekayi* to *Nuttainia* should invalidate his genus. The validity of his genus must rest solely upon the value of the generic distinctions proposed, the species selected as type, and the relative date of the publication of the genus.

Hall's testimony that *Nuttainia* was established before *Cryptolithus* (*New York Paleontology,* vol. 1, p. 235) is invalidated by the fact that he lists only Green's *Monograph,* not his *Synopsis* in the *American Journal of Geology and Natural History,* even 15 years after the publication of the latter, although both copies of the Journal in the Walker Museum library are from the original Hall library. Moreover, in 1842, in the *Report of the Second District* by the New York Geological Survey, p. 390, Prof. Ebenezer Emmons uses the term *Trinucleus tesselatus,* Green, rather than *Trinucleus concentricus,* Eaton.

I suspect that Green's claim of priority for *Cryptolithus tesselatus* is correct, although at this late date positive proof appears to be lacking. But one thing at least is certain, if the term *Cryptolithus* has priority, then the specific term *tesselatus* also has priority. The combination *Cryptolithus concentricus* is inadmissable.

Regarding the term *Trinucleus,* which has become so firmly established, it can scarcely be said to have been adequately described by Lhwyd, in 1698. It was Sir R. I. Murchison who first gave this term a generic significance, in his work on the Silurian System, in 1839, seven years after the publication of the generic terms proposed by Green and Eaton. The ready acceptance of this term by American authors could have been due only to the great prestige of Murchison and a complete ignorance of Lhwyd's article. Certainly, it was an injustice to the American authors, to retain the term Trinucleus, after its extremely inadequate description became known.

Calymene platycephala, sp. nov.

(Plate II, fig. 7.)

In the Saltillo limestone, at Clifton, Tennessee, there is found a species of *Calymene* with a flattened cephalon. The middle part of the cephalon here figured belongs to the Hall collections in the American Museum of Natural History, in New York City, and is numbered 1409. The anterior part of the glabella and that part of the anterior border of the cephalon which lies between the facial sutures, have straightened outlines. The anterior pair of furrows limiting the glabellar lobes is short and rather indistinct. The second and third pair are distinct but shallow. The nuchal furrow and its extension across the posterior part of the fixed cheeks are still more distinct, but much less conspicuous than in most species of *Calymene*. The grooves limiting the glabella are broad and shallow. The convexity of the glabella above these grooves does not exceed 2 mm., the border of the cephalon anterior to the glabella is not turned up but lies in about the same plane as the lateral margins of the cephalon. The shell appears smooth to the unassisted eye, but under a strong magnifier is minutely dotted with lighter colored spots. The postero-lateral ends of the fixed cheeks and all of the movable cheeks are absent.

A pygidium found in the same strata and at the same locality (plate III, fig. 21) may belong to this species. There is a strong axial lobe, with about 6 segments, and an undivided posterior portion. The lateral lobes are divided into 6 segments, with a faint indication of a seventh. The groove limiting the axial lobe curves around its posterior end and separates it from the posterior margin of the pygidium. The lateral margins are deflected sharply downwards, the width of this deflected margin narrowing posteriorly, and disappearance along the median parts, behind the axial lobe. A ridge, interrupted at the furrows between the pleural segments, occurs along the line of deflection.

This species evidently is closely related to *Calymene christyi*, from the lower part of the Waynesville bed, near Oxford, Ohio.

Calymene senaria, Conrad.

(Plate II, fig. 14.)

In the American Museum of Natural History, in New York City, there is a specimen from the Trenton at Middleville, New York, which is labelled as *Calymene callicephala*, and numbered 843-7. The length of the specimen is about 59 mm.; of this, 15 mm. belong to the cephalon, 31 mm. to the thorax, and almost 14 mm. to the pygidium. The width of the thorax immediately behind the head is 30 mm., narrowing gradually to about 21 mm. toward the pygidium. The most striking feature of this specimen is the nasute outline of the anterior part of the cephalon. This nasute border extends fully 4 mm. forward from the anterior border of the glabella. Viewed from the side, it does not appear strongly retrorse, as in the specimens from the Waynesville bed or from the Maysville formation. Of the cephalon, only the cast of the lower side of the chitinous integument forming the upper surface of the cephalon is preserved, but this is sufficient to indicate the chief characteristics of the specimen as described above. Specimens of this type have been identified by Clarke with *Calymene senaria,* Conrad. In the specimen at hand, the postero-lateral outlines of the cephalon, including the genal spines, are not well preserved, but there is no reason to believe that they differ essentially from the form figured as *Calymene senaria* by Clarke, in the *Paleontology of Minnesota,* vol. 3, part 2, p. 700, in 1897. Since this figure is based on a cast of the original specimen, it must be authentic.

Calymene abbreviata, sp. nov.

(Plate III, fig. 17.)

In the upper part of the Greendale bed, at the railroad cut a mile south of Rogers Gap, Kentucky, at the telegraph pole marked as 61 miles south of Cincinnati, a species of *Calymene* occurs which is characterized by the straightened, truncated anterior margin of the glabella. The anterior margin of the fixed cheek is more prominent and abrupt. The anterior border of the cephalon is somewhat flattened, and, owing to the truncation of the anterior margin of the glabella, appears a little more remote from the latter than in most other species. A little antero-lateral to the lateral extremities of the frontal lobe of the glabella, the anterior border of the cephalon presents on each side a low blunt elevation. In consequence, an anterior view of the border appears slightly concave above.

Calymene callicephala, Green.

Calymene callicephala was described by Dr. Jacob Green in an article on North American Trilobites, published in the *Monthly Journal of Geology*, in 1832. The type, located at that time in the Philadelphia Museum, the present location of which however, is unknown, was labelled as coming from Hampshire, Virginia. Hampshire is one of the northeastern counties of West Virginia, bordering on the Potomac river, and is not known to contain any Cincinnatian rocks. This type is represented by cast No. 2 of the set accompanying Green's *Monograph of North American Trilobites*. This cast certainly does not represent the common trilobite of the Cincinnati group, as exposed at Cincinnati, Ohio. if, indeed, it correctly represents any species whatever. Only the posterior and middle pairs of the lateral lobes of the glabella are indicated. There is no trace of the anterior pair of lobes. It is not probable that any species with these characteristics exists. The front of the glabella should extend in front of a line connecting the anterior parts of the palpebral lobes. Moreover, there is an even slope from the front of the glabella to the anterior margin of the cephalon, while there should be a deep depression here, defining the anterior margin of the glabella, and separating it from the anterior portion of the cephalon. The nasute anterior outline of the cephalon is not as strongly pronounced as in the nasute Calymenes from the Trenton of New York. As a matter of fact, there are specimens of *Calymene* from the vicinity of Cincinnati, which have an equally triangular outline in case of the cephalon, but in none of these are the anterior lobes of the glabella, nor the still more anterior frontal lobe of the glabella, absent.

It is evident from the original description that Green was impressed by the anterior attenuation of the cephalon, in other words, by its nasute outline; and by the absence of the anterior part of the glabella, as found in *Calymene blumenbachii*. His statement that the oculiferous tubercles are rather lower down on the cheeks than usual does not describe the Cincinnatian form, whatever this expression may mean.

The specimens in the cabinet of the New York Lyceum and in that of J. P. Wetherill, from the vicinity of the Miami river, near Cincinnati, Ohio, and those from Indiana, correlated with the Hampshire type by Green in his original description undoubtedly belong to the same type as the series from Cincinnati described by Meek as *Calymene senaria*, but if the type ever be found it may turn out to belong to an entirely different horizon.

Calymene meeki, nom. nov.

(Plate III, fig. 18.)

For the species so well described by Meek from the Cincinnatian rocks of Ohio, as *Calymene senaria*, the term *Calymene meeki* is here proposed. As types, the large specimens from the Fairmount bed, with a rather extended posterior outline of the cephalon, resulting in acute genal angles are chosen.

Calymene meeki — retrorsa.

(Plate III, fig. 19.)

In the Waynesville bed, a form of *Calymene meeki* occurs which differs chiefly in the narrower posterior width of the cephalon, resulting in more obtuse genal angles, inclined to be more or less rounded toward the tip. The anterior border of the cephalon is more strongly reflexed, bringing it closer to the anterior margin of the glabella. The specimen figured was obtained in the Clarksville division of the Waynesville bed, east of Dunlapsville, Indiana, half a mile above the mouth of Silver creek. It is doubtful whether it will be possible to differentiate the Waynesville specimens from those in the Maysville, but the present is at least an attempt.

Calymene is rare in the upper part of the Richmond formation, from the Liberty to the Elkhorn, but occasional specimens may be found. These usually are rather small.

Dalmanites carleyi — rogersensis.

A species of *Dalmanites*, very closely allied to *Dalmanites* (*Pterygometopus*) *carleyi*, occurs in the lower part of the Eden section between Rogers gap and Sadieville; about ten feet above the railroad track at the first large exposure west of bridge 54, west of Million tunnel, in Madison county; and at the cut east of Hatton; all in Kentucky. Compared with *Dalmanites carleyi*, from the Fairmount bed at Cincinnati, Ohio, the Eden specimens differ chiefly in their larger size, the cephalon attaining a width of 20 mm., while the cephalon of the Fairmount specimens usually do not exceed 15 mm. That part of the glabella which lies posterior to the frontal lobe is more elongate and slightly less constricted at the nuchal segment. The pygidium also is closely similar to that of the Fairmount form. The chief interest in these Eden specimens consists not in their distinctness from the Fairmount species, but in their very close relationship, increasing the number of species in the Rogers Gap fauna, which may be regarded as precursors of the Fairmount fauna.

Pasceolus camdenensis, sp. nov.

(Plate II, fig. 6.)

In the American Museum of Natural History, in New York City, there is a specimen of *Pasceolus* which is labelled as coming from Camden, Ohio. It is almost spherical, the vertical diameter being 30 mm., and the transverse diameter nearly 28 mm. Forty-five to fifty plates lie along a line encircling the specimen horizontally. The plates usually are hexagonal in outline, and are arranged in crossing diagonal rows, but locally the outline may be more nearly pentagonal and occasionally five plates may appear to meet at a central point. Five plates occur in a length of 10 mm. along the diagonal lines, varying to 7 in the same length where they are of smallest size. The exposed surfaces of the plates are convex. The nature of the impressions which would be left by these plates upon the matrix filling the cavity of the fossil is unknown. The specimen is not pointed at one end, as though for attachment to some object, as in case of the species *Pasceolus halli.*

Pasceolus halli possesses convex plates bent so as to be slightly depressed towards the angles and elevated toward the sides. Fragments of an unknown species of *Pasceolus* from Anticosti, presenting the same form of plates, possess a series of minute granules visible only under a higher magnifier. These granules are arranged in diagonal series diverging on each of the radial elevations, just mentioned, toward the depressed angles of the plates. This ornamentation suggests that this division of *Pasceolus* may belong to Cystids.

Pasceolus globosus, the type of the genus *Pasceolus,* belongs to the group of species characterized by the presence of somewhat concave plates, often marked by six stellate radiating lines of depression extending from the center of each plate toward the angles.

It is not certain that the group typified by *Pasceolus halli* is congeneric with *Pasceolus globosus. Pasceolus darwini* and *Pasceolus claudei* belong to the *Pasceolus globosus* group. The plates of *Pasceolus gregarius* and *Pasceolus intermedius* have not been described.

Labechia (?) corrugata, sp. nov.

(Plate I, fig. 11.)

In the Whitewater bed, along Dutch creek, near Wilmington, Ohio, an encrusting form of some Stromatoporoid occurs which differs from any of the species described hitherto from Cincinnatian rocks in the irregularity of the nodules or ridges ornamenting its surface. As in other species described from the same rocks, the surface is ornamented by small granules or papillae. These are rather coarse, and vary greatly in number and size in different parts of the same specimen, but usually about 3 or 4 occur in a length of 2 mm. In addition to the granules there are nodules, more or less irregular in shape, varying to short ridges, or connected so as partially to enclose small papillate areas from 1.5 to 2 mm. in diameter. In *Alveolites granulosa,* James, *Stromatopora subcylindrica,* James, *Labechia ohioensis,* Nicholson, and *Labechia montifera,* Ulrich, the nodules are large, broad and relatively distant from each other, varying from 4 in a length of 20 mm. to the same number in a length of 30 mm. In *Stromatopora scabra,* the nodules have a regular conical form and are rather regularly distributed, about 5 or 6 in a length of 15 mm. In *Labechia corrugata* from 5 or 6 to 3 irregular noduliferous elevations occur in a length of 10 mm. *Stromatopora indianensis,* James, was described as massive, not incrusting. The thickness of the specimens here described as *Labechia corrugata* is 3 mm. The generic reference of these specimens to *Labechia* is merely owing to the superficial resemblance of these specimens to the various species of Cincinnatian stromatoporoids which at one time or another have been referred to this genus. Probably none of these are congeneric with the type of that genus, *Labechia conferta.*

A large specimen, collected by Dr. George M. Austin, from the same locality, is crossed by irregular, vermiform ridges, distant in some places, more numerous, and more or less intertwining in others. These ridges appear in addition to the coarse papillae and the small irregular nodules characteristic of the species. For this form the term *Labechia* (?) *corrugataglypta* has been selected.

PLATE I.

FIG. 1. *Suecoceras* (?) *inaequabile,* Miller. Lower end of siphuncle, laterally compressed. From the *Orthoceras fosteri* layer, at the base of the Clarksville division of the Waynesville bed, in the Stony Hollow, northwest of Clarksville, Ohio.

FIG. 2. *Suecoceras* (?) *inaequabile,* Miller. Lower end of siphuncle. Madison, Indiana, from the Waynesville bed.

FIG. 3. *Orthoceras (Ormoceras?) hitzi.* Smooth orthoceracone, with vertical striae due to weathering. Madison, Indiana, from the Hitz layer, at the top of the Saluda bed.

FIG. 4. *Dawsonoceras hammelli.* Dog Falls, on Saluda creek, southwest of Hanover, Indiana, from the Hitz layer at the top of the Saluda bed.

FIG. 5. *Orthoceras (Loxoceras) milleri.* Orthoceracone, with traces of the smooth shell. Two miles south of the Crow distillery, 7 miles south of Frankfort, Kentucky, from the Perryville bed.

FIG. 6. *Spyroceras bilineatum-frankfortensis.* South of Glenn creek, at the Crow distillery, 6 miles south of Frankfort, Kentucky, from the Logana bed.

FIG. 7. *Cyrtoceras hitzi.* Convex side of cyrtoceracone. *B,* the same, enlarged. Madison, Indiana, from the Hitz layer, at the top of the Saluda bed.

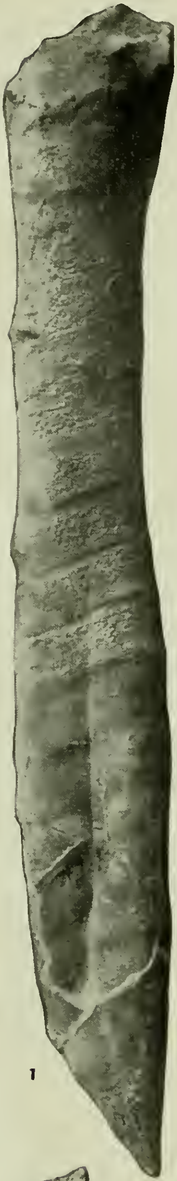
FIG. 8. *Clidophorus.* New species, resembling *Clidophorus neglectus* in outline, but with the posterior umbonal ridge less strongly defined, and with the clavicle directed slightly forward from the beak, limiting a shorter anterior muscle scar. *B,* the same, inverted and enlarged. Clifton, Tennessee, from the Saltillo bed.

FIG. 9. *Opisthoptera concordensis.* Left valve, with the outline not preserved and not known. In the creek bed south of the railroad bridge, east of Concord, Kentucky. From the upper part of the Arnheim bed, five and a half feet below the *Strophomena concordensis* zone, associated with *Streptelasma vagans.*

FIG. 10. *Pterinea (Caritodens) demissa,* Conrad. Left valve. Clifton, Tennessee, from the Arnheim bed.

FIG. 11. *Labechia (?) corrugata.* Dutch creek, northwest of Wilmington, Ohio, from the top of the Whitewater bed.

PLATE I.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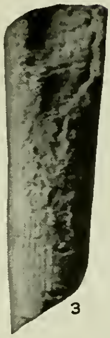
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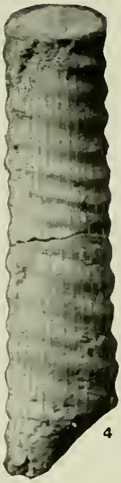
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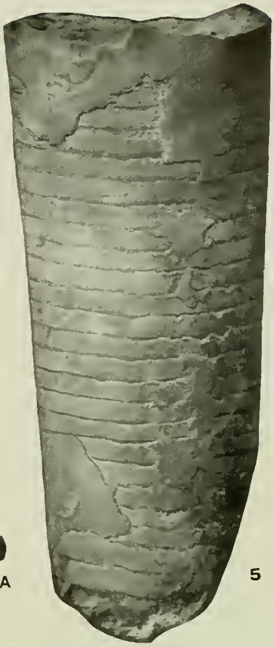
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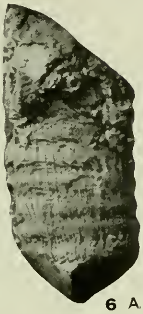
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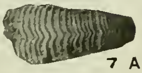
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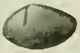
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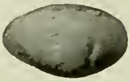
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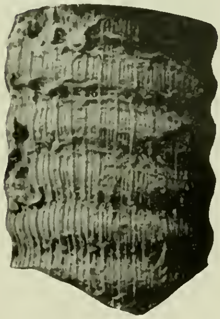
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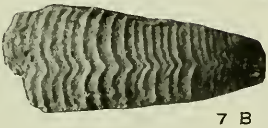
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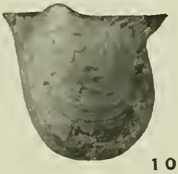
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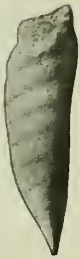
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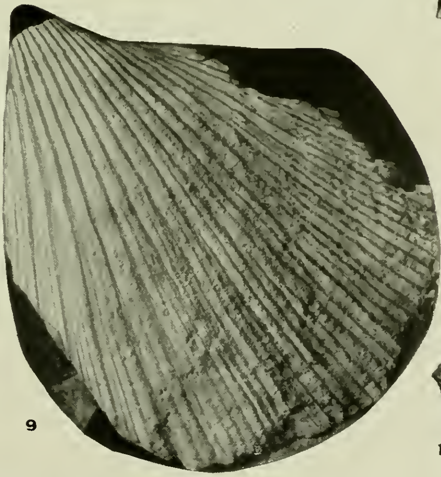
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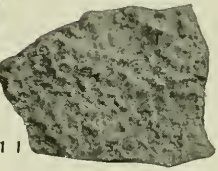
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PLATE II.

Fig. 1. *Hebertella occidentalis,* Hall. *A,* brachial valve. *B,* pedicel valve, Type specimen illustrated in *New York Paleontology,* vol. 1, plate 32A, by figures 2c, 2k. Cincinnati, Ohio.

Fig. 2. *Hebertella occidentalis,* Hall. *A,* brachial valve; *B,* pedicel valve. Type specimen illustrated in *New York Paleontology,* vol. 1, plate 32 A, by fig. 2e. Cincinnati, Ohio.

Fig. 3. *Catazyga headi-schuchertana,* Ulrich, lateral view. Madison, Indiana, from the Waynesville bed, Madison, Indiana.

Fig. 4. *Rafinesquina declivis,* James. Pedicel valve, enlarged 1.8 diameters. The type specimen described by James. Boyd's station, Kentucky, from the argillaceous limestones beneath the Eden formation.

Fig. 5. *Hebertella sinuata,* Hall. Brachial valve. Type specimen illustrated in *New York Paleontology,* vol. 1, plate 32 B, figs. d, h, k, and plate 32 C, fig. o. Cincinnati, Ohio.

Fig. 6. *Pasceolus camdenensis.* Camden, Ohio.

Fig. 7. *Calymene platycephala.* Clifton, Tennessee, in the Saltillo bed.

Fig. 8. *Hebertella subjugata.* Hall. Brachial valve. Type specimen illustrated in *New York Paleontology,* vol. 1, plate 32 C, fig. 1a. Cincinnati, Ohio.

Fig. 9. *Plectorthis jamesi,* Hall. *A,* Brachial valve, enlarged; *B,* Pedicel valve of the same specimen. Type specimen, illustrated in the *Ohio Paleontology,* vol. 2, plate 1, by figs. 21, 22. Cincinnati, Ohio.

Fig. 10. *Cyclocoelia sordida,* Hall. Brachial valve. Type. Cincinnati, Ohio. Magnified 1.7 diameters.

Fig. 11. *Cyclocoelia ella,* Hall. Type, with 21 plications, belonging to series No. 1506-3, in the American Museum of Natural History, in New York City. Cincinnati, Ohio. Magnified 1.7 diameters.

Fig. 12. *Cyclocoelia ella,* Hall. One of the same series of types, numbered 1056-3, but with 27 plications, approaching *Cyclocoelia sordida-multiplicata.* Cincinnati, Ohio. Magnified 1.7 diameters.

Fig. 13. *Plectorthis equivalvis,* Hall. *A,* Brachial valve; *B,* lateral view. Type, in the American Museum of Natural History, in New York City. Cincinnati, Ohio.

Fig. 14. *Calymene senaria,* Conrad. American Museum of Natural History, in New York City. From the Trenton, at Trenton Falls, New York.

Fig. 15. *Zygospira modesta,* Hall. *A,* Brachial valve, enlarged; *B,* pedicel valve, of the same specimen. Type. Cincinnati, Ohio.

Fig. 16. *Rhynchotrema dentata,* Hall. Brachial valve. Type. From the region of the Cincinnati geanticline, possibly from the Whitewater bed.

Fig. 17. *Lingula modesta,* Ulrich. Frankfort, Kentucky, from the Logana bed.

Fig. 18. *Lingula waynesboroensis.* Three and a half miles northwest of Waynesboro, Tennessee, near the home of W. D. Helton, on Beech creek, in the Saltillo bed.

Fig. 19. *Catazyga uphami-australis.* *A,* brachial valve; *B,* lateral view. High Bridge, Kentucky, near the lower part of the exposures on the road down to the lock, in the Camp-nelson division of the Highbridge formation.

Fig. 20. *Leptobolus lepis-cliftonensis.* *A,* pedicel valve; *B,* cast of interior of pedicel valve; *C,* cast of interior of brachial balve. Clifton, Tennessee, from the Saltillo limestone. Magnified 5 diameters.

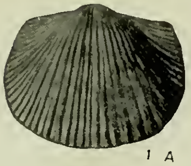
Fig. 21. *Conocardium richmondensis.* *A,* lateral view; *B,* cardinal view. Magnified 1.6 diameters. Elkhorn creek, 15 feet below the Brassfield or Clinton bed, in the Elkhorn bed, southeast of Richmond, Indiana.

Fig. 22. *Orthoceras (Ormoceras ?) hitzi.* Vertical section passing obliquely through the siphuncle, crossing the center near the lower end of the specimen. The distinctness of the detail is over-accentuated in the drawing. Madison, Indiana, from the Hitz layer, at the top of the Saluda bed.

Fig. 23. *Cyrtoceras hitzi.* *A,* cross-section near the upper end, the concave side of the specimen not being preserved; *B,* convex or dorsal side; *C,* lateral view of the imperfect specimen. Madison, Indiana, from the Hitz layer, at the top of the Saluda bed.

Fig. 24. *Orthoceras (Loxoceras ?) milleri.* *A,* cross-section, showing relative size of the siphuncle where passing through the septum; *B,* vertical section through the siphuncle, showing strongly nummuloidal segments, as in *Actinoceras.* Two miles south of the Crow distillery, 7 miles south of Frankfort, Kentucky, from the Perryville bed.

PLATE II.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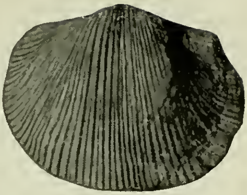
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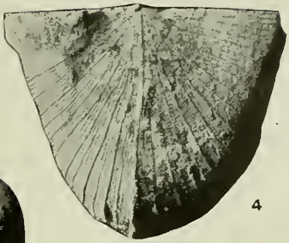
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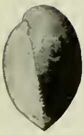
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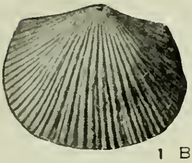
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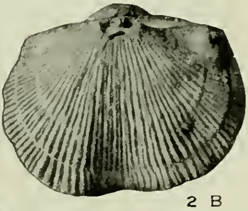
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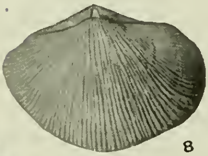
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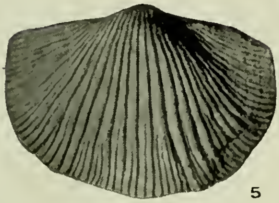
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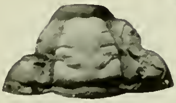
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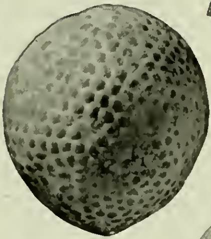
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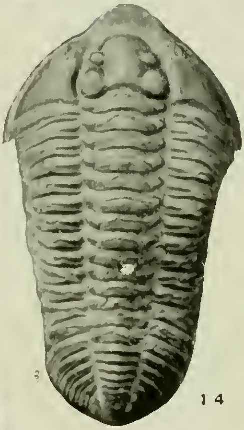
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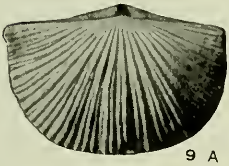
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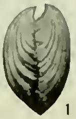
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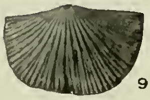
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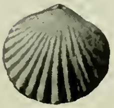
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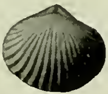
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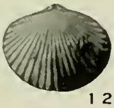
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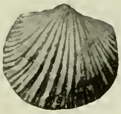
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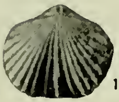
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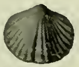
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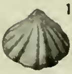
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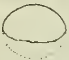
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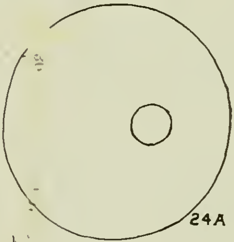
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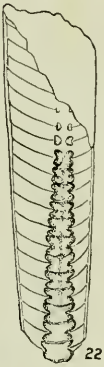
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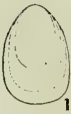
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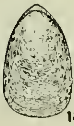
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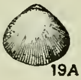
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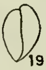
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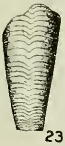
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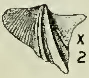
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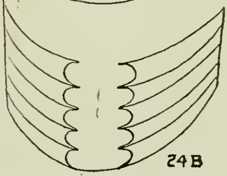
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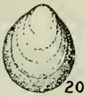
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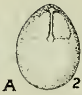
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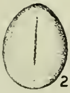
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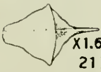
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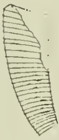
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PLATE III.

Fig. 1. *Platystrophia laticosta,* Meek. *A,* brachial valve; *B,* pedicel valve. Cincinnati, Ohio, Fairmount bed.

Fig. 2. *Platystrophia laticosta,* Meek. Brachial valves. From the group of specimens numbered 40479 in the U. S. National Museum, said by R. S. Bassler to be from the Waynesville bed, at Waynesville, Ohio.

Fig. 3. *Platystrophia clarksvillensis.* Brachial valve. Stony Hollow, a mile and a half southeast of the railroad station at Fort Ancient, Ohio, in the lower or Fort Ancient division of the Waynesville bed.

Fig. 4. *Platystrophia clarksvillensis.* Brachial valve. Sewell run, south of the pike from Wilmington to Clarksville, Ohio, in the middle or Clarksville division of the Waynesville bed.

Fig. 5. *Platystrophia cypha,* variety. At the deep railroad cut three miles south of Maysville, one mile north of Summit, Kentucky, in the upper division of the Arnheim bed.

Fig. 6. *Platystrophia acutilirata,* Conrad. Brachial valve. Richmond, Indiana, from the upper part of the Whitewater bed.

Fig. 7. *Platystrophia acutilirata,* Conrad. Pedicel valve. Pennsylvania railroad cut, at Huffman hill, in the eastern part of Dayton, Ohio, in the upper part of the Whitewater bed.

Fig. 8. *Platystrophia acutilirata-prolongata,* James. Richmond, Indiana, from the upper part of the Whitewater bed.

Fig. 9. *Platystrophia* sp. A unique specimen from the *Homotrypa wortheni* horizon at the base of the Elkhorn bed, on Elkhorn creek, three miles southeast of Richmond, Indiana.

Fig. 10. *Orthorhynchula linneyi,* James. Brachial valve. One mile north of Paint Lick, Kentucky, in the upper part of the Fairmount bed.

Fig. 11. *Catazyga headi-schuchertana,* Ulrich. Madison, Indiana, along the Hitz road, west of the railroad incline, in the upper part of the Waynesville bed.

Fig. 12. *Rhynchotrema dentata,* Hall. Richmond, Indiana, in the upper part of the Whitewater bed. Lateral view.

Fig. 13. *Rhynchotrema dentata-arnheimensis.* Lateral view. Along the creek south of Arnheim, Ohio, in the Arnheim bed.

Fig. 14. *Catazyga uphami-australis.* Brachial views. *B,* specimen with a low, broad median elevation; *C,* enlarged view of *A,* the type. High Bridge, Kentucky, in the Camp-nelson bed.

Fig. 15. *Cyclocoelia sectostriata,* Ulrich. Brachial views. *B,* enlarged view of *A.* Cincinnati, Ohio, Fairmount bed.

Fig. 16. *Cyclocoelia crassiplicata.* Cincinnati, Ohio, in the Fairmount bed. Types.

Fig. 17. *Calymene abbreviata.* At mile post 61, one mile south of Rogers Gap, in the Greendale division of the Cynthiana formation.

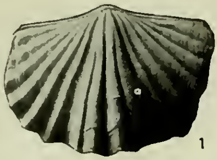
Fig. 18. *Calymene meeki.* Cincinnati, Ohio, in the Fairmount bed.

Fig. 19. *Calymene meeki-retrorsa.* On Silver creek, east of Dunlapsville, Indiana, in the middle or Clarksville division of the Waynesville bed.

Fig. 20. *Orthorhynchula ?* Unknown brachiopod with simple plications, the four median plications slightly elevated. From a well in the Fulton or Lower Eden, 1 mile south of Lower Blue Lick Springs, Kentucky.

Fig. 21. *Calymene platycephala ?* Pygidium, found at the same horizon as the middle part of the cephalon of *Calymene platycephala.* Clifton, Tennessee, in the Saltillo bed.

Fig. 22. *Schizocrania rudis,* Hall. Upper valve, slightly crushed.. *B,* view of *A,* enlarged. Clifton, Tennessee, in the Saltillo bed.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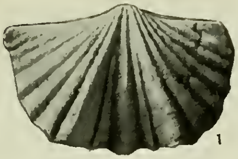
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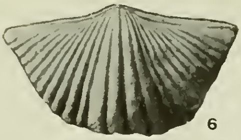
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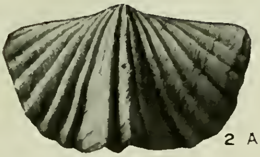
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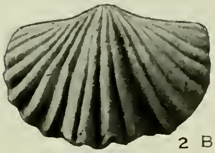
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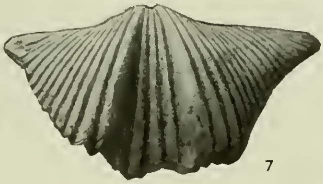
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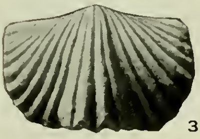
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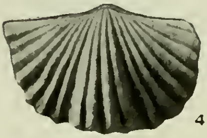
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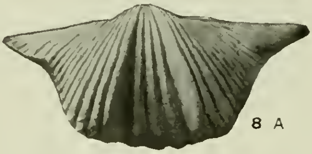
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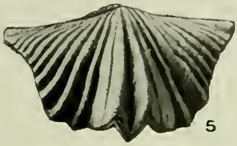
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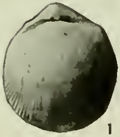
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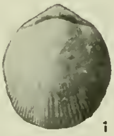
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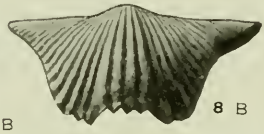
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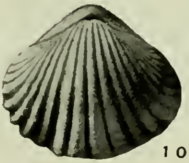
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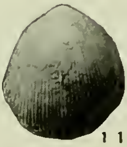
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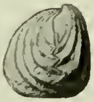
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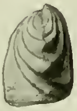
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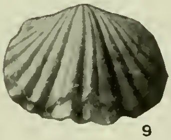
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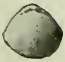
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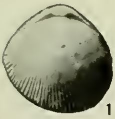
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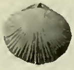
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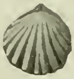
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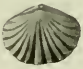
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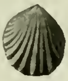
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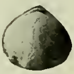
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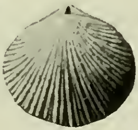
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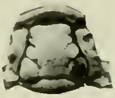
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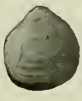
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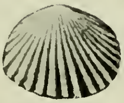
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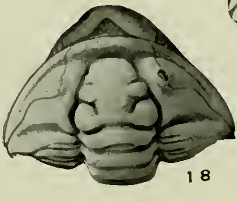
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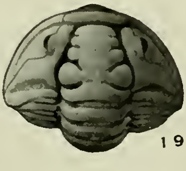
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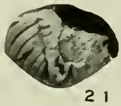
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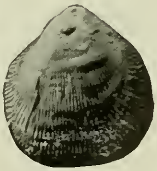
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PLATE IV.

FIG. 1. *Platystrophia colbiensis-precursor.* Brachial valve. At mile post 627, between Colby and Winchester, Kentucky, in the Greendale division of the Cynthiana formation.

FIG. 2. *Platystrophia colbiensis.* *A,* brachial valve; *B,* pedicel valve. Along the railroad, a mile and a half southwest of Carlisle, Kentucky, in the Greendale division of the Cynthiana formation.

FIG. 3. *Platystrophia colbiensis-mutata.* Brachial valves. Five miles west of Winchester, Kentucky, along the railroad to Colby, in the Greendale division of the Cynthiana formation.

FIG. 4. *Platystrophia profundosulcata-hopensis.* Brachial valve. Cincinnati, Ohio, in the Mount Hope bed.

FIG. 5. *Platystrophia crassa,* James. *A,* cardinal view; *B,* brachial valve. Cincinnati, Ohio, near the middle of the Fairmount bed.

FIG. 6. *Platystrophia unicostata,* Cumings. Brachial valve. Above the conspicuous *Platystrophia ponderosa* horizon in the Bellevue bed, near foot of road from New Hope church to Willard branch of the south fork of Laughery creek, in Ohio county, Indiana.

FIG. 7. *Platystrophia cypha-conradi.* Brachial valves. Along the Bardstown pike, half a mile south of Smithville, in Bullitt county, Kentucky, in the Arnheim bed.

FIG. 8. *Platystrophia acutilirata-inflata,* James. *A,* cardinal view; *B,* brachial valve. Types, No. 1561, from the Walker Museum of Chicago University. This form occurs in the upper part of the Whitewater beds at Richmond, Indiana. James collection.

FIG. 9. *Platystrophia acutilirata,* Conrad. Brachial valve.

FIG. 10. *Platystrophia cypha,* James. *A,* brachial valve; *B,* anterior view. Warren county, Ohio. Type, No. 2326, from the Walker Museum at Chicago University. James collection.

FIG. 11. *Platystrophia cypha-versaillesensis.* Brachial valves. Versailles, Indiana, from the Liberty bed.

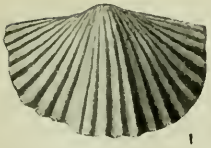
FIG. 12. *Platystrophia cypha,* James. Mount Sterling, Indiana, from the Bellevue horizon, immediately over the conspicuous *Platystrophia ponderosa* horizon.

FIG. 13. *Platystrophia cypha-versaillesensis.* Intermediate between the forms *conradi* and *versaillesensis.* North of Hogan creek, on the road from Moores Hill to Holman, Indiana, about 25 feet below the *Hebertella insculpta* horizon, in the Blanchester division of the Waynesville bed, associated with an abundance of *Leptaena richmondensis.*

FIG. 14. *Platystrophia cypha-conradi.* Half a mile south of Smithville, Kentucky, in the Arnheim bed. Brachial valves.

ORDOVICIAN FOSSILS.
A. F. FOERSTE

PLATE IV.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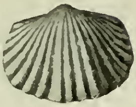
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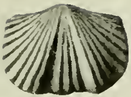
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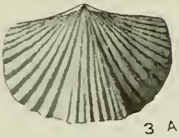
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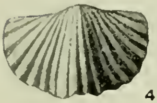
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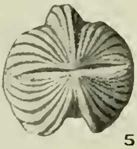
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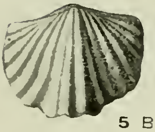
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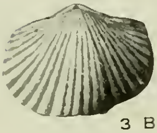
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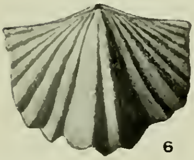
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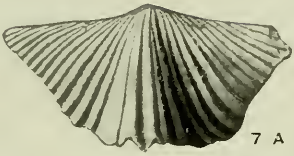
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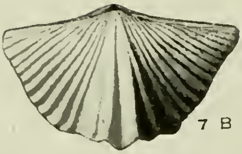
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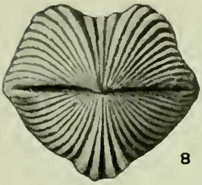
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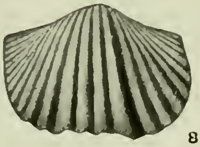
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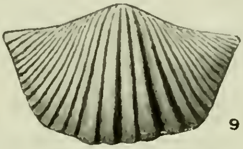
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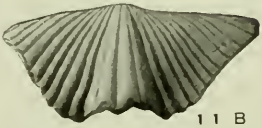
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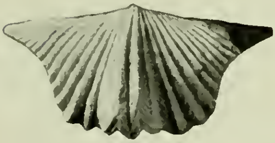
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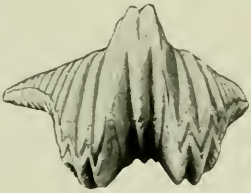
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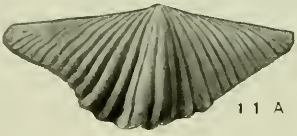
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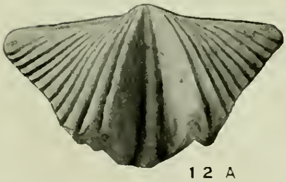
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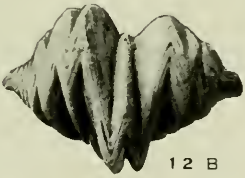
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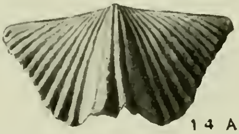
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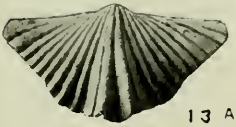
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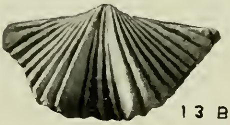
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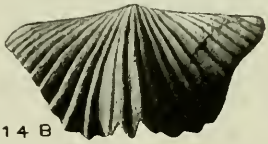

14 B

PLATE V.

Fig. 1. *Trematis punctostoriata,* Hall. Clifton, Tennessee, from the Saltillo bed.

Fig. 2. *Trematis fragilis.* Ulrich. Figured in *Ohio Paleontology,* vol. 2, plate 1, fig. 9, as *Trematis punctostriata.* No. 102 of the James collection at Chicago University. Cincinnati, Ohio.

Fig. 3. *Trematis fragilis,* Ulrich. Lower valve, showing the pedicel scar. Cincinnati, Ohio.

Fig. 4. *Trematis fragilis,* Ulrich. Upper valve. Cincinnati, Ohio.

Fig. 5. *Lingula covingtonensis,* Hall and Whitfield. Interior of valve, enlarged 1.8 diameters. West Covington, Kentucky, between 25 and 50 feet above low water in the Ohio river, from the strata beneath the two foot crinoidal layer which underlies the Fulton bed.

Fig. 6. *Lingula covingtonensis,* Hall and Whitfield. Interior of valve, enlarged 2 diameters. Frankfort, Kentucky, from the Logana bed.

Fig. 7. *Lingula waynesboroensis.* Brachial valve, with the tip of the pedicel valve exposed at the top, enlarged 2 diameters. Three and a half miles northwest of Waynesboro, Tennessee, near the home of W. D. Helton, on Beech creek.

Fig. 8. *Crania granulosa-cumberlandensis.* Upper valve, enlarged 2 diameters. A mile and a quarter southwest of Cumberland City, Tennessee, along the railroad south of the crossing of the Erin pike, from the Stones River group.

Fig. 9. *Leptaena tenuistriata?* Pedicel valve. *B,* the same, with a part of the anterior margin restored; enlarged. Clifton, Tennessee, from the Saltillo bed.

Fig. 10. *Hebertella alveata-richmondensis.* Type. Brachial valve. Richmond, Indiana, from the top of the Whitewater bed, associated with *Rhynchotrema dentata.*

Fig. 11. *Platystrophia cypha,* James. Type. Cardinal view. No. 2326, James collection, Chicago University. Warren county, Ohio.

Fig. 12. *Rafinesquina declivis,* James. Pedicel valves. *A,B,* the type. *B,* lateral view, showing deflection of the sides due to pressure. *C,* triangular shell with the margin only moderately deflected. *D,* another specimen of the same series, presenting the normal outline, except at the cardinal angles, which usually are more nearly rectangular. Series No. 2392. James collection, at Chicago University. Boyd's station, Kentucky, from the strata underlying the Eden formation.

Fig. 13. *Rafinesquina winchesterensis.* *A,* brachial valve; southwest of Antioch church, west of the Million tunnel, in Madison county, Kentucky. *B,* brachial valve, interior; west of Winchester, Kentucky. *C,* pedicel valve, south of Pleasant Valley, Kentucky. From the Greendale bed.

Fig. 14. *Rafinesquina winchesterensis-filistriata.* Interior of brachial valve. Thirteen and a half miles northeast of Paris, Kentucky, measured along the railroad to Carlisle. From the Greendale bed.

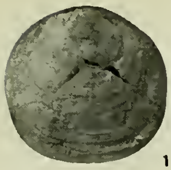
Fig. 15. *Rafinesquina winchesterensis-filistriata.* *A,* pedicel valve. *B,* brachial valve of the same specimen. Clays Ferry, on the Kentucky river, in Madison county, Kentucky. From the Greendale bed.

Fig. 16. *Plectorthis dichotoma* (?). *A,B,* brachial valves. *C,D,* pedicel valves. West of Dillsboro station, Indiana, about 10 feet below the *Platystrophia ponderosa* beds, in the upper Fairmount.

Fig. 17. *Hebertella alveata-richmondensis.* Brachial valve. Richmond, Indiana, from the same horizon as the type represented by figure 10 on this plate, but with the shell moderately prolonged at the hinge-line. Upper part of Whitewater bed.

ORDOVICIAN FOSSILS.
A. F. FOERSTE.

PLATE V.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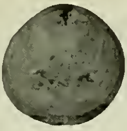
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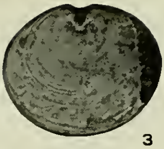
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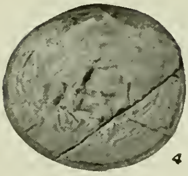
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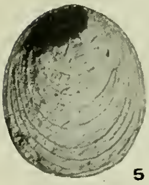
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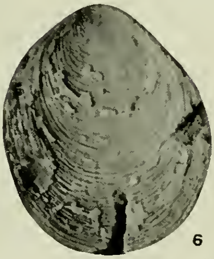
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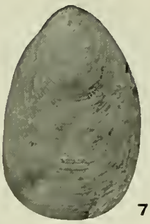
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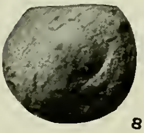
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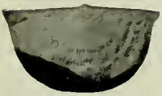
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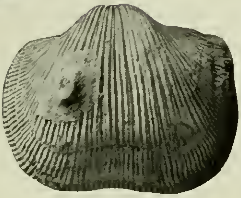
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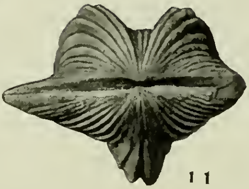
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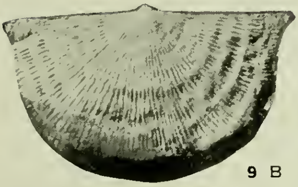
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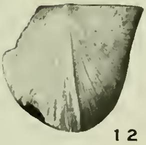
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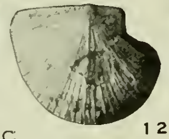
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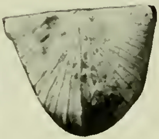
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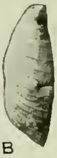
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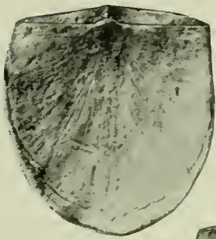
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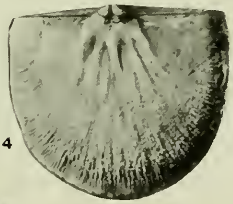
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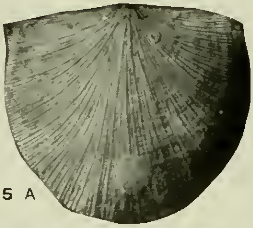
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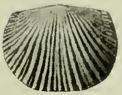
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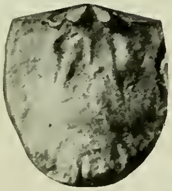
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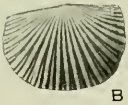
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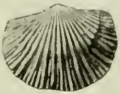
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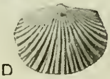
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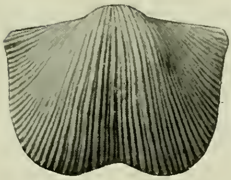
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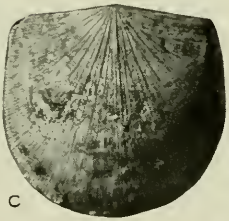
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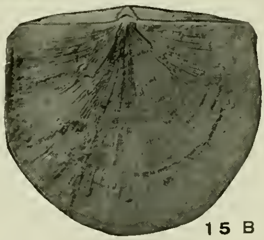

15 B

BULLETIN, SCIENTIFIC LABORATORIES, DENISON UNIVERSITY,
VOL. XVI, ARTICLE 2.

PLATE VI.

FIG. 1. *Plectorthis neglecta,* James. *A,D,* brachial valves. *B,* pedicel valve. *C,* view of hinge area. Series of types, James collection, No. 2399, Chicago University. *E,* interior of pedicel valve. James collection, No. 127. Cincinnati, Ohio, from Mount Hope bed.

FIG. 2. *Plectorthis equivalvis-pervagata.* Primary plications of moderate prominence. Brachial valve. Gurley collection, No. 8127, Chicago University. Cincinnati, Ohio, from the Fairmount bed.

FIG. 3. *Plectorthis equivalvis-latior.* Primary plications more prominent, varying toward *Plectorthis fissicosta.* Brachial valve. Gurley collection, No. 8127, Chicago University. Cincinnati, Ohio, from the Fairmount bed.

FIG. 4. *Plectorthis fissicosta,* Hall. Wider grooves between the primary plications, the secondary plications added a considerable distance from the beak, and occupying a distinctly lower position. Brachial valve. Gurley collection. No. 8127, Chicago University. Cincinnati, Ohio, from the Fairmount bed.

FIG. 5. *Plectorthis plicatella,* Hall. Brachial valves. Gurley collection, No. 8127, Chicago University. Cincinnati, Ohio, from the Fairmount bed.

FIG. 6. *Cyclocoelia sordida-multiplicata.* With 29 to 34 plications. *A,* brachial valve. *B,* pedicel valve. Gurley collection, No. 8115. *C,* brachial valve, Chicago University. *D,* pedicel valve, apparently a narrow, pathological specimen. James collection, No. 130, Chicago University. Cincinnati, Ohio, from the Fairmount bed.

FIG. 7. Enlarged views of the preceding.

FIG. 8. *Plectorthis sordida,* Hall. *A,* brachial valve. *B,* same, enlarged. Cincinnati, Ohio, from the Fairmount bed.

FIG. 9. *Cyclocoelia crassiplicata,* sp. nov. *A,C,* brachial valves. *B,* pedicel valve. Cincinnati, Ohio, from the Fairmount bed.

FIG. 10. Enlarged views of the preceding.

FIG. 11. *Platystrophia morrowensis,* James. *A,* brachial valve. *B,* same, enlarged. Type, James collection, Chicago University. Warren county, Ohio, from the upper part of the Corryville bed.

FIG. 12. *Platystrophia morrowensis,* James. Form with longer hinge-line named *Platystrophia similis* by Ulrich. *A,* pedicel valve. *B,* same, enlarged. James collection, Chicago University. Probably found associated with the preceding.

FIG. 13. *Platystrophia acuminata,* James. *A,* pedicel valve. *B,* same, enlarged. Type, James collection, No. 1562, Mount Auburn, at Cincinnati, Ohio, probably from the Mount Auburn bed.

FIG. 14. *Platystrophia annieana,* James. *A,* pedicel valve. *B,* anterior view of same. *C,* brachial valve of another specimen. Types James collection, No. 84, Chicago University. Blanchester, Ohio, from the upper or Blanchester division of the Waynesville bed.

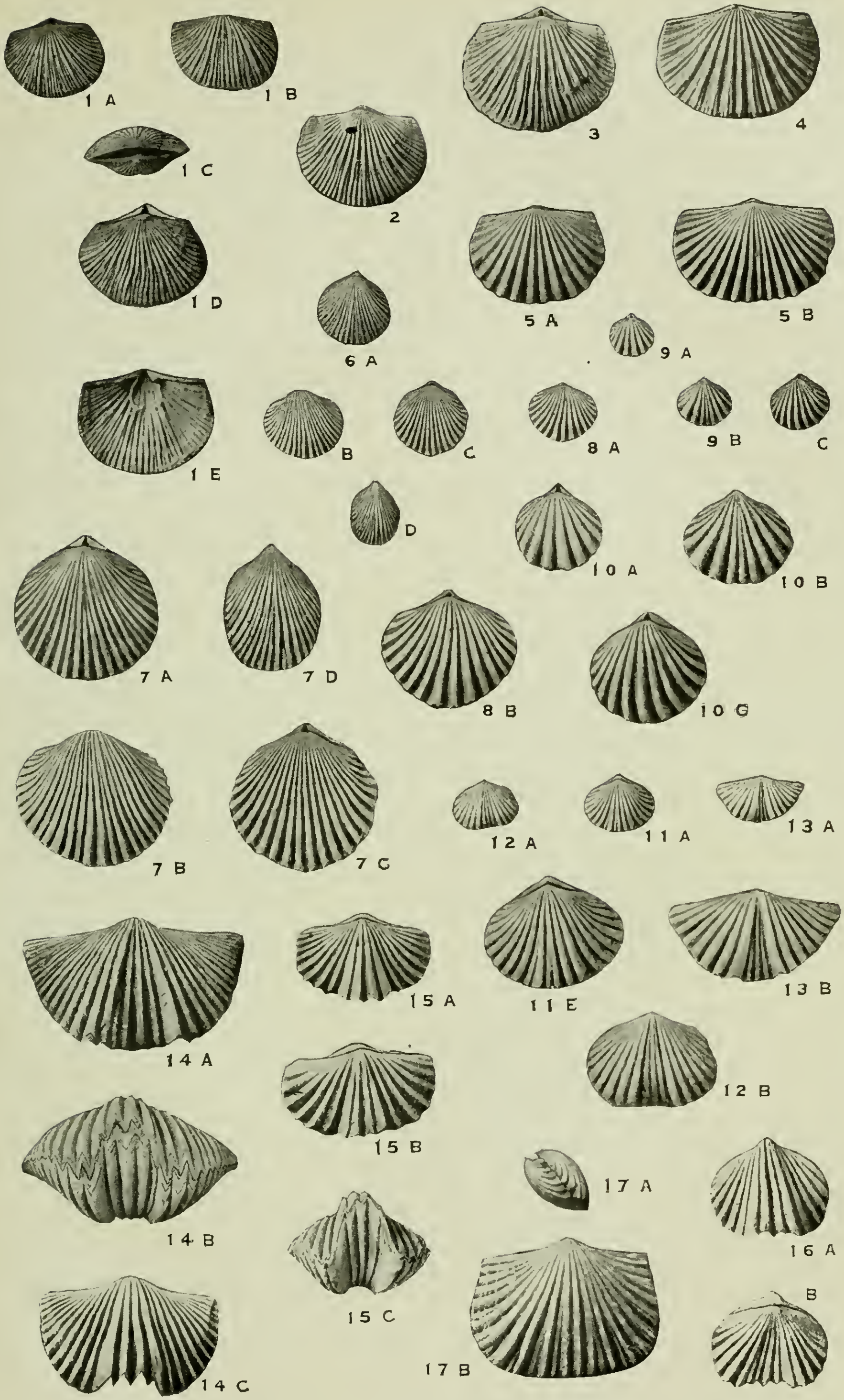
FIG. 15. *Platystrophia profundosulcata,* Meek. *A,B,* brachial valves. *C,* anterior view. James collection, No. 186, Chicago University. Labelled as types, but not the specimens figured by Meek. Cincinnati, Ohio, from the Fairmount bed.

FIG. 16. *Zygospira cincinnatiensis,* Meek. *A,* pedicel valve. *B,* brachial valve. James collection, No. 164, Chicago University, from a series of specimens marked as types, but differing apparently from the specimen described by Meek. Cincinnati, Ohio, from the Fairmount bed.

FIG. 17. *Plectorthis equivalvis,* Hall. *A,* lateral view. *B,* pedicel valve of the same enlarged. Closely resembling the type described by Hall, but broader. Cincinnati, Ohio, from the Fairmount bed.

ORDOVICIAN FOSSILS.
A. F. FOERSTE.

PLATE VI.


1 A
1 B
1 C
1 D
1 E
2
3
4
5 A
5 B
6 A
B
C
D
7 A
7 B
7 C
7 D
8 A
8 B
9 A
9 B
C
10 A
10 B
10 C
11 A
11 E
12 A
12 B
13 A
13 B
14 A
14 B
14 C
15 A
15 B
15 C
16 A
B
17 A
17 B

BULLETIN, SCIENTIFIC LABORATORIES, DENISON UNIVERSITY,
VOL. XVI, ARTICLE 2.

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THE ABANDONED SHORELINES OF THE OBERLIN QUADRANGLE, OHIO[1]

FRANK CARNEY

Many students have given attention to the shifting series of lakes that followed up the retreating Wisconsin ice sheet. The broader questions involved in this history have been investigated and the general outlines of the succeeding lake stages, and their individual overflow channels, have been mapped.[2] In some parts of the Great Lakes' basin more detailed mapping has been done.[3] In the Maumee Valley of Ohio, G. K. Gilbert has studied in considerable detail the raised beaches.[4] On the Oberlin sheet the only work heretofore published is that (1) of E. E. Wright,[5] who located several beaches at scattered points, thus getting enough of evidence to make a very general map; and (2) of J. S. Newberry, who briefly explains Wright's map.[6]

The surface features of the Oberlin sheet (plate VII) have not been altered much during post-glacial times. The area has a general and quite uniform northward slope, declining from an altitude of 850 feet to 573 feet, the level of Lake Erie. The drainage of practically the whole sheet focuses into one major stream, the Black river. A narrow strip on the west side is controlled by Beaver creek. The course of Black river, south of the Warren shoreline, reflects preglacial topography. It follows the axis of a depression which was sufficiently deep and broad to form a bay in each of the three lake stages; this irregularity of shoreline was least in the Warren stage and greatest in the Maumee stage.

The stratigraphy of the sheet is obvious both in the topography and in the resulting outline of the high-level lakes. Throughout two-thirds of the sheet's area, the Berea sandstone formation is either on or very near the surface. Preglacial weathering of the Berea cut it back towards Elyria, making a depression followed now by the Black river. This depression is confined northward, and is bounded, by sandstone outcrops near Avon Center and Sheffield Junction; several outliers of the Berea extend southwestward from Sheffield Junction. For many miles south of this escarpment the Berea sandstone has a very shallow covering of drift.

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[1] Read at the meeting of the American Geological Society, Boston, December, 1909, with the permission of the State Geologist of Ohio. The author is responsible for the facts given.

[2] Whittlesey, Charles, *The American Journal of Science*, vol. X (1850), pp. 31-39. Taylor, F. B., *Bull. Geol. Soc. Am.*, vol. VII (1897), pp. 31-58. Leverett, F., *Monograph XLI*, U. S. Geological Survey (1902), pp. 710-775.

[3] Alden, W. C., *The Chicago Folio*, No. 81, U. S. Geol. Survey, 1902. *The Milwaukee Special Folio*, No. 140, U. S. Geol. Survey, 1906. Goldthwait, J. W., "The Abandoned Shorelines of Eastern Wisconsin," *Wis. Geol. and Nat. Hist. Survey*, (1907), pp. IX-134. Atwood, W. D., and Goldthwait, J. W., "Physical Geography of the Evarston-Waukegan Region", *Illinois State Geol. Survey*, Bulletin No. 7, (1908), pp. 28-69.

[4] *Geological Survey of Ohio*, vol. I, (1873), pp. 535-56.

[5] *Geological Survey of Ohio*, vol. II, (1874), map opposite p. 58.

[6] *Ibid*, pp. 207-8.

Wherever a shoreline coincided with the outcropping Berea, the waves produced a load of stand for transportation. Beach ridges and other shore forms were constructed more quickly than when the waves worked only on shale or on glacial drift. In every case the most conspicuous beaches reflect this rock influence. A similar influence is seen also in the islands, formed by outliers of the Berea sandstone, and in barriers that were constructed in the shallow water overlying outliers that did not form islands.

THE MAUMEE SHORELINE

At most points where this shoreline has been studied in Ohio, it consists of two beach ridges, separated by a vertical difference of ten to twenty feet; the upper shoreline has an altitude of about 770 feet. These two ridges generally are present in the Oberlin sheet.

A broad embayment characterized the Maumee shoreline in the Oberlin quadrangle. This bay, during the higher Maumee stage, extended about four miles southward from Elyria.

Upper Maumee stage.—Commencing on the western edge of the sheet, for nearly five miles I have indicated a single beach for the Maumee stage. In this distance the shoreline is not very well developed. The glacial drift does not appear ever to have been thick here, and the outcropping shale did not furnish the waves an abundant supply of material for shore structures. Nearly two miles east of Amherst, at the highway leading directly north, I have mapped two ridges, but I believe that this complexity represents cusp structures rather than distinct beaches. On the hypothesis that the lower Maumee shoreline, in this distance of five miles, did not develop a very sharp beach-ridge, it is possible that weathering has made its detection difficult, and that closer study might give a location to both levels.

Near the boundary between Amherst and Elyria townships the Maumee shoreline turns directly south, and thus continues to the valley of the West Branch; this section is called "West Ridge." Throughout most of this distance it is a beach, but a cliff, cut in glacial drift, is found not far south of the Lake Shore railway (Southern Division). Just beyond this cliff-phase, a short ridge, on the inland border of the beach, indicates the earliest position of the Maumee level, when the bay extended still farther west. Stream erosion has removed part of the southern end of West Ridge.

Murray Ridge, parallel to this, appears to have originated as an off-shore barrier of the higher Maumee shoreline, which later grew above water and finally became the shoreline proper. It has a strong development, increasing in height and complexity southward. About one mile of the northern part was steepened by wave-work. In texture, the deposits grow finer towards the south. The muck soil between West and Murray ridges indicates a lagoon history; an arm of the lake was shut off completely at the northern end, as shown by the bar joining the ridges; there is evidence that the southern end was once more nearly enclosed than now; some short spits are appended to the inland slope of the beach, one of which may formerly have been connected with the isolated ridge of sand and gravel, outlined by the 750-foot contour, about one mile long, and parallel to West Ridge. Murray Ridge was a shoreline in the closing period of the upper Maumee stage as well as during the lower stage.

Between the east and west branches of the Black river, the upper Maumee level is represented by a well developed shoreline extending southwest from Laporte. This part of the beach consists prevailingly of fine sand. The ridge has a very much sharper front than back slope (fig. 1 A), because of steepening by wave erosion. Between this beach and the southern end of West Ridge, stream work has removed whatever shore development existed in this, the shallowest part of the bay.

East of the river the shoreline is known as "Butternut Ridge," and has a very strong development. For most of this distance the beach is composed of fine gravel and very fine sand; its front slope, as shown by a typical cross-section, is sharp; and there is generally present a lower inner ridge (fig. 1 B). Toward the eastern border of the sheet, the lake side of the ridge is a cliff cut in the drift and shale; a regular beach caps the cliff, showing that the wave-erosion took place just before the close of this Maumee stage.

Lower Maumee stage.—"Chestnut Ridge," which parallels

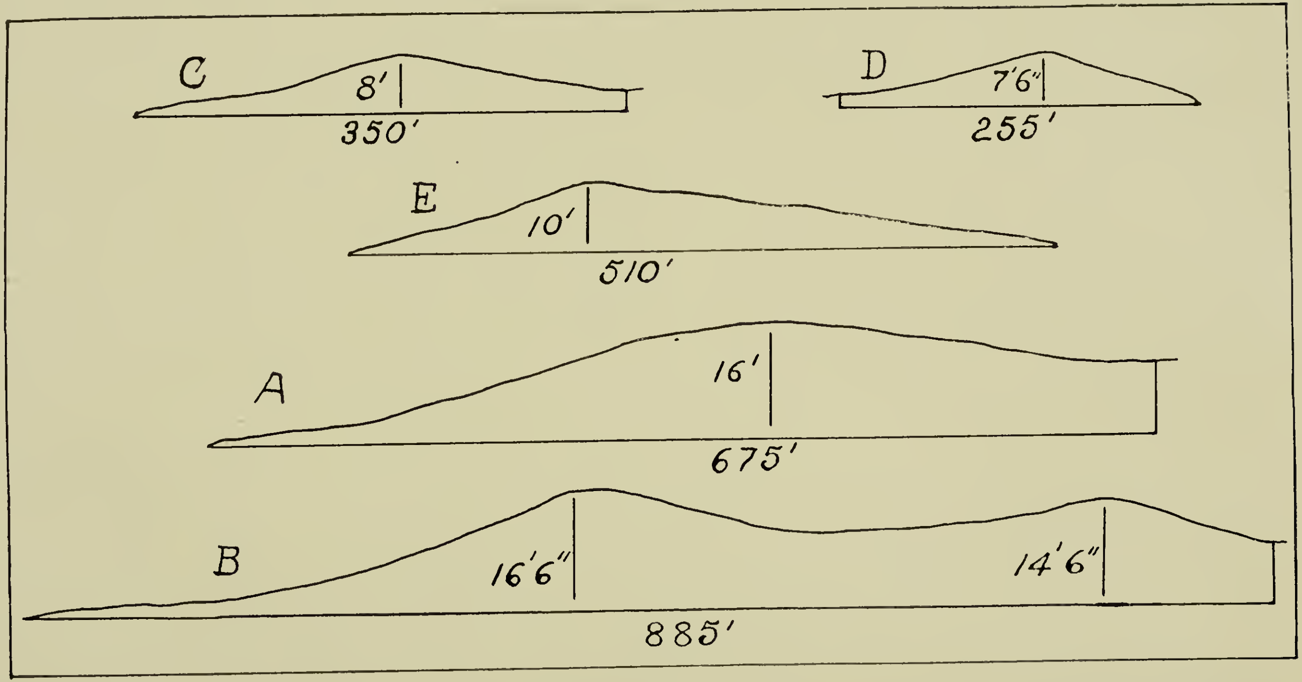

C
8′
350′
D
7′6″
255′
E
10′
510′
A
16′
675′
B
16′6″
14′6″
885′

Fig. 1

Cross-sections of the Maumee shoreline, horizontal and vertical measurements as indicated. Consult plate VII for the location of these cross-sections.

Butternut Ridge and is less than half a mile distant, represents the lower Maumee level. It has a slighter development, and consists of finer deposits; eight feet is the usual height (fig. 1 C). Its western end shows successive positions due to the development of spits into the deepening waters of the bay. Many lagoons formerly existed between Butternut and Chestnut Ridges.

Between the two branches of the river I was unable to locate a continuous shoreline of the lower Maumee; it is represented by only one short ridge, consisting mostly of weathered clay, wave-eroded from the subjacent shale, directly south of Elyria.

Sugar Ridge is obviously an off-shore barrier of the lower Maumee stage. It has a symmetrical development (fig. 1 D, E) and, from the numerous bowlders, particularly along its eastern half, I infer that the barrier may have been initiated by an irregular deposit of glacial drift.

Extending northward from a point near the middle of Murray Ridge I have mapped a structure which resembles a barrier through part of its course; elsewhere its strength of development implies a regular shoreline. This inference is based partly on other Maumee deposits directly north, deposits which indicate this level declined gradually, thus converting part of the barrier into a beach.

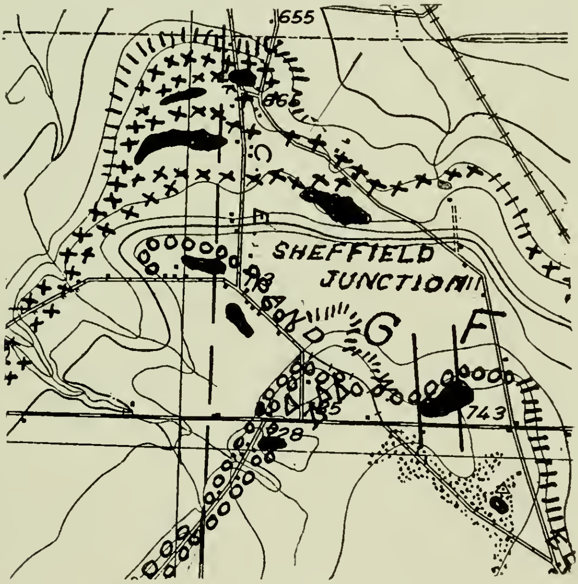


FIG. 2

Cuspate foreland of the Warren stage, south of Lorain. Parts also of the Whittlesey and Maumee shorelines southeast of Sheffield Junction.

Directly north from this locality my map shows scattered Maumee deposits. All of these rest immediately upon the Berea sandstone which in this region has scarcely any covering. The two areas west of the north-south highway consist of quite coarse rubble. The crescent-shaped area east of the highway is made up of slightly finer material; if I had been able to trace beach deposits between this and the arm of sand and gravel extending northward from near the middle of Murray Ridge, I would not hesitate to make it the shoreline of the lower Maumee. The ridge that extends north, crossing the electric line, and bearing thence to the west, parallels a lagoon for seven-tenths of a mile. This ridge increases in strength of development northward; its west or inland slope is short and steep. A recently constructed railroad, about twenty rods south of the electric line, reveals a section; at this point it consists of coarse, well-rounded stones; finer gravel is found as the ridge turns westward. The two short spits are composed of fine sand; one of these so encloses a lagoon (fig. 2) that it is difficult to conceive of its originating in any other way than in very shallow water. It is quite evident that this region of Berea sandstone, north of the Lake Shore railway, formed a shallow place, like a submerged cape, in lake Maumee, and that these scattered areas of beach deposits were constructed during its declining stage.

Islands.—About a mile east of North Amherst, the area marked "Quarry" on the topographic map (fig. 3) formed a small island in the Maumee stage. Its slopes were steepened by wave work; to its eastern end is appended a spit. The part of the island's surface that was above water now bears wind-shifted sands.

THE WHITTLESEY SHORELINE

The Black river depression was occupied by a broad bay during the Whittlesey stage. The outcropping sandstone on the west formed a peninsula, making a break in the regular east-west direction of the shore. The general altitude of Lake Whittlesey is about 730 feet; a beach structure characterizes its shoreline on the Oberlin sheet.

West of Black river.—Near the west margin of the sheet (plate VII) Beaver creek has cut the beach for a short distance. Immediately on either side of this creek the shore ridge consists chiefly of fine sand. To the east, as the shoreline bears northward, there is evidence of a glacial origin of the beach materials; the large number of scattered bowlders along the shore terrace suggest wave-action on till.

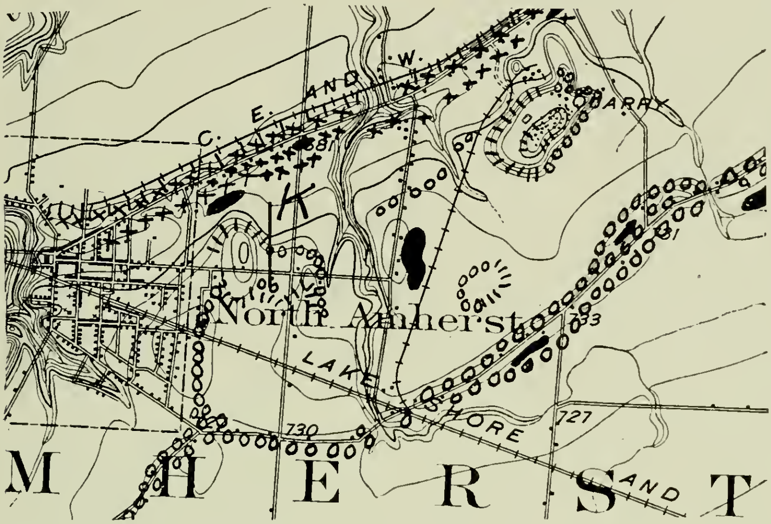


Fig. 3

Shoreline features in vicinity of North Amherst.

The highway trending to the northeast follows the Whittlesey beach ridge. After crossing the Lake Shore railway the ridge is complex, having a lower inland beach. Directly southeast of the "Quarry" a broad cusp was formed (fig. 3). One-half mile southeast of Sheffield Junction the beach contains so much sand that it was drifted by the wind into dunes (fig. 2). Just east of this dune area the shore-ridge has a very sharp development as shown by the profiles (fig. 4 F, G); the original position of the shoreline here was farther inland as suggested by the long lagoon south of the beach. Thence southward for one-half mile the Whittlesey level is marked by a cliff cut in the sandstone; beyond this is a gravel and sand ridge which is followed by the "Lake Road" into Elyria. Near the point where the cliff-phase gives place to structural deposits there are several ridges and intervening lagoons. About one and one-half miles northwest of Elyria, outcropping sandstone again formed a cliff, for about 60 rods, in the Whittlesey shoreline.

The exact course of this beach in the vicinity of Elyria cannot be mapped, chiefly because of stream erosion.

East of Black river.—From the river to the eastern side of the sheet the Whittlesey level is marked by a continuous beach structure, the off-shore slope of which for much of this distance shows steepening by wave-work towards the close of the Whittlesey period.

Throughout most of this distance there is an inner beach ridge of earlier development. About one and one-half miles west of North Ridgeville a third ridge appears. Locally these ridges indicate greater activity of wave and along-shore work, thus piling up heavy beaches and eventually moving the shoreline outward; a cross-section near the east side of the sheet (fig. 4 H) is an example; a similar relationship of the two ridges exists west of North Ridgeville near the second highway leading south. Locally the inner ridge is lower (fig. 4 I); while in places a single beach exists (fig. 4 J).

In the vicinity of Sheffield Junction I have mapped a spit that grew to the northwest from the shoreline proper (fig. 2). This spit, after it crosses the highway leading north to Lorain, has a strong development. Following the decline of the Whittlesey level, a marsh condition existed south of this ridge, as evidenced by the extensive muck areas. The highway from this point to North Amherst formerly followed the ridge, having a more irregular course; later it was changed to its present more direct course across the marsh. From the eastern end of this latter ridge the sandstone forms a low escarpment, swinging southward to the shoreline proper; that this escarpment is the result of wave-work is doubtful.

Islands.—Several outliers of Berea sandstone formed islands in Lake Whittlesey. One such area on the western edge of the sheet eventually became a part of the shoreline itself, through being doubly tied to the shore by bars, a feature that is observed on the next sheet west, the Vermillion. A cliff in the sandstone nearly surrounds the part of this island shown in the Oberlin sheet; a short reach of structural deposits is found on both the north and south sides of the island west of the wave-cut slope.

Just east of North Amherst is another island of this lake stage (fig. 3). The northern side of this is a wave-cut cliff; on the southern side wave-cutting is also recorded, not in rock but in unconsolidated material. A beach is found on the east side, with a spit

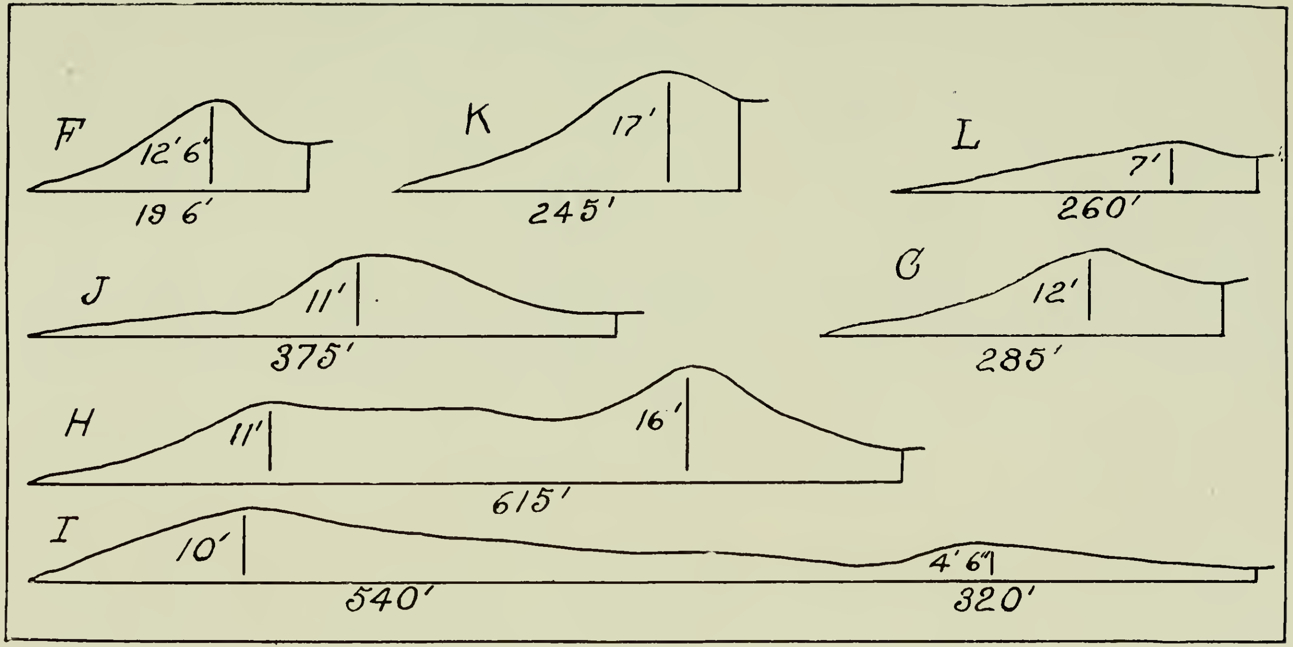

F
12'6"
19 6'
K
17'
245'
L
7'
260'
J
11'
375'
G
12'
285'
H
11'
16'
615'
I
10'
540'
4'6"
320'

FIG. 4

Cross-sections of the Whittlesey shoreline, horizontal and vertical measurements as indicated. Plate VII gives the location of these cross-sections, extending eastward for about twenty rods, then turning to the south, its course being deflected by on-shore currents in the deeper water; a profile of the beach west of the north-south highway (fig. 4K) shows wave-erosion. This island was tied to the shore by a spit which grew landward from its southwestern side; the texture of this bar is coarser near its island end; at the southern end it consists of fine sand and gravel, forming a cusp-like union with the beach.

About one-half mile east of this island, I have indicated on the map another small area which was above water during the latter part of the Whittlesey stage. On the eastern side of this there is evidence of some wave-work on the sandstone; elsewhere its shore is marked by beach material. In origin this island appears to represent a local arching of the sandstone. The whole surface is strewn with slightly worn blocks of the thin layers found in the upper part of the Berea formation.

The only island on the sheet belonging to the Maumee level, as already noted, is one-half mile farther northeast; during the Whittlesey stage its area was about four times as great. Its western half has a wave-cut cliff; elsewhere its shore is marked by structural deposits. Short spits extended from the northeastern quarter, one growing almost directly north and the other bearing to the east. Wind-deposited sands are noted also in connection with the Whittlesey beaches, about this island.

The road extending southward from Avon (plate VII) leads across a long ridge due to an arching of the Berea sandstone; the attitude of the beds is revealed in a railway cut made directly across the ridge. This arching caused a shallow place in Lake Whittlesey, and led to the construction of a barrier. Apparently the Whittlesey level fell slightly and a spit was developed to the southwest; this spit consists of very coarse material, the product of wave-work on the thin beds of the Berea; the part of its course that parallels a north-south highway is a strong ridge; north of this point its cross-section (fig. 4 L) shows that the lake-level fell enough to subject the tied end of the spit to wave-attack. Opposite the northern end of "Rocky Ridge" is a shorter ridge of gravel and sand which originated as an off-shore barrier. Paralleling the southern part of Rocky Ridge, and east of it, is another off-shore barrier.

Between the Wheeling Railroad, and the Lorain and Elyria

Electric line, about one-half mile south of the northern boundary of Elyria township, I have mapped two areas of Whittlesey gravels. The eastern one lies between the 690 and 700-foot contours, according to the map. It is quite certain that the sketching on the topographic map is in error at this point. The Whittlesey structures here shown are spits of rather coarse materials, built from an island outlier of Berea sandstone the shape of which is roughly shown by the 700-foot contour. This outlier has a long east-west axis. According to the hand level its top is approximately on a level with the "Lake" road, one-half mile southwest—i. e., the altitude of the outlier is about 730 feet. From its southwestern corner another spit of coarse gravel material was developed; these gravels terminate near the Wheeling track. Apparently a wave-cut cliff once showed entirely across the north side of the island, where a quarry is now located.

THE WARREN SHORELINE

The altitude usually given the Warren stage is 660 to 670 feet. According to the contours, some of the ridges which I have mapped under the Warren stage rise a few feet above the 670-foot contour.

The Black river depression did not make much of a bay in Lake Warren. The irregularity of its shoreline is due to the irregular outline of the Berea outcrops. At two points this sandstone had a cusp-like extension into the lake: at Avon Center and at Sheffield Junction. West of the latter place the escarpment is cut up into outliers. Between these two capes the sandstone has been removed for some distance southward, a fact that accounts for the course taken by the drainage.

On this sheet Lake Warren had no islands. Only shale outcrops beneath the Berea, the Bedford here not having the "Bluestone" phase which it contains farther east. Weathering proceeds so easily and so regularly in mud rocks that the surface keeps uniform, except during the early part of an erosion cycle.

West of Black river.—West of Beaver creek the Warren level appears first in an inner, lower ridge. A short distance north of this is a strongly developed beach steepened by wave erosion; an outlier of sandstone nearby on the Vermillion sheet furnished an abundant supply of beach-making materials.

From North Amherst to the neighborhood of Sheffield Junction, the Warren beach consists of two and sometimes of three ridges. The outer shows the effects of wave-work; for three miles the base of the cliff is cut into drift. The numerous glacial bowlders attest the removal of drift by currents and waves.

Directly south of Lorain the northward extension of the Berea formation led to a variety of off-shore structures which gave the shoreline a cusp-like protrusion farther into the lake (fig. 2). This area is a typical example of the cuspate foreland; its growth represents the progressive enclosing of lagoons. After a static profile had been reached, wave-work made the cliff which now borders the foreland. The initial position of the Warren beach here is easily traced by a ridge that continues east-west south of the foreland.

Proceeding eastward the Warren shoreline bears to the south; for a short distance, just west of the Wheeling railway, it has a cliff-phase. This railroad crosses three beach ridges and intervening lagoons. It is evident that in the early part of the Warren level the shoreline had temporary positions farther south in the Black river Bay. Several sand and gravel ridges trend southward; some of these terminate at the edge of the river cliff; others have been eroded by its tributary streams, or by earlier positions of the river itself. The multiplicity of ridges on either side of the river show that this shoreline was gradually given a straighter course by the development of spits into bars which, during post-glacial times, have been dissected by the Black river. The irregular course of the Black river in crossing the Warren shoreline reflects the influence of these beaches.

East of Black river.—From the river to the vicinity of Avon many distinct ridges have been mapped. Part of these had a spit origin; others were off-shore barriers first and beaches later. I have indicated some of the numerous lagoons that existed between the ridges. These ridges increase in degree of development towards the north; the one farthest south is short and low; the next one north is broken, and has a sharp bend due to a slight irregularity in the land surface. I made careful search west of the river to find correlating ridges; the map shows all that exist now.

In the vicinity of Avon Center is another cuspate foreland (fig. 5). This, however, differs from the one south of Lorain in that its northern extension includes an outcrop of Berea sandstone which early in the Warren stage was probably an island, and was

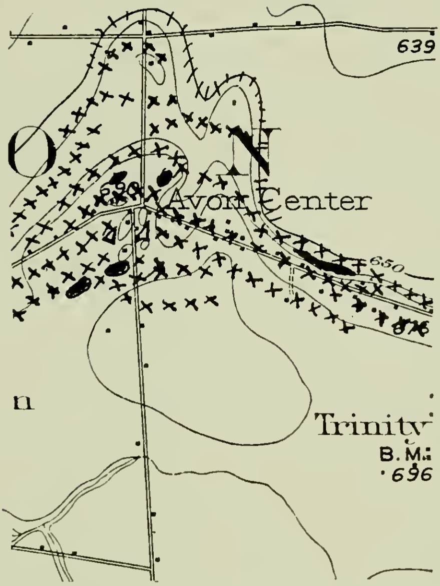


FIG. 5
Cuspate foreland of the Warren stage

eventually tied to the shore. The ridges, south as well as north of Avon Center, are of the cuspate type, showing how this foreland was progressively extended by the deposition-work of interfering currents. The shoreline between the foreland and the eastern margin of the sheet consists continuously of two distinct ridges, and for part of the distance of three ridges.

Before the close of the Warren stage, as shown by nearly the entire reach of the shoreline, the waves and along-shore currents had accomplished their maximum of structural work; then cliff-cutting prevailed. Even where the beaches are best developed the off-shore slope is much steepened. For several miles east of the river a strip of muck or lagoon soil borders the beach cliff; north of the muck is sandy clay, both apparently at the same level. Initially the clay was a low barrier, but high enough to make a marsh. Accordingly it appears that Lake Warren had an intermediate slight fall in level before the great drop which converted its marginal parts into a lake plain.

DRAINAGE CYCLES

The Oberlin quadrangle shows concisely the relationship that arises from succeeding base-levels each of which interrupted a normal development of drainage lines; it also shows the influence that formations of simple structure and varying hardness have on the growth of valleys, a factor that may be more effective relatively than time in producing the several stages in the cycle of erosion. The erosion cycles here are not as simple as they would be if each had commenced on a normal consequent surface. Preglacially the region had been subject long to weathering; its rock structure is such that the area has preserved this older erosion pattern; to a slight extent only did the distribution of glacial drift change this former topography.

The Maumee base-level.—The definite level of the upper Maumee in this region must have been preceded by a minor body of water occupying the depression indicated now by the branches of the Black river. This condition, however, did not endure long, as no shorelines marking the lake have been found.

The Maumee shoreline has an altitude of about 770 feet. South of this the surface configuration is influenced by the Berea sandstone, over which is a covering of shale so thin that a slight amount of channeling places the streams on the more resistant rock. The Berea here is heavy and has a mild dip to the south. The northward slope of the preglacial surface was gentle.

The amount of slope for several miles south of lake Maumee was-so slight that the drainage pattern formed was but little more developed than a true consequent surface would give. The fall of these streams was so gentle that the beach diverted them towards particular points, at which they cut the ridge when the Maumee level declined. At Laporte the streams from east and west converge and cross the beach ridge. This branch of the Black river has not made much of a channel in the Berea sandstone; north of its intersection with the Lorain and Wheeling railway, glacial drift forms its banks; south of this point, it has cut slightly into the Berea.

The West Branch apparently is following an earlier valley which was partly filled with drift. Its irregular course still preserves the meanderings of the consequent stream which flowed into lake Maumee. Its tributaries are quite numerous relative to the small areas which each controls; and the width of its valley corresponds to the long period of erosion.

The Whittlesey base-level.—Lake Maumee was lowered about 40 feet in establishing this level; the drop was not accomplished at once, as is evidenced by the lower Maumee beach. Furthermore, the multiplicity of barrier beaches, belonging to the Maumee level, indicates a halt in the change.

The two branches of the Black river converge more when brought under the control of the Whittlesey base-level, a fact due to the shape of the preglacial basin which occasioned the local bay in Lake Maumee. The 40 feet of fall added to the stream slope did not have much effect on their erosive powers in the Maumee part of their courses. This 40 feet is in the Berea sandstone, which is quite resistant, and in all post-glacial times has not been cut down so as to materially increase the gradient upstream.

Laterally from the depression in which Elyria lies the streams connected with the Whittlesey base-level were few and of slight development. Beaver creek, on the west side of the sheet, has made more of a valley than either branch of Black river; this is due to a steeper initial slope, and to the shorter distance through which it had to channel the Berea sandstone.

The Warren base-level.—The difference in altitude between this and the Whittlesey level is about 60 feet; the drop appears to have been accomplished quickly. The accession of drainage territory was not great because west of Black river the Whittlesey and Warren shorelines are close together.

In this change of level, Black river was lengthened by about four miles; the slope of this added length originally could not have been over 60 feet. The stream therefore took a somewhat irregular course, which it still preserves. Its channel lay across a slight depth of glacial drift beneath which the rock is an easily eroded shale; consequently this four-mile section was not long in reaching the new base level. During the existence of Lake Warren, the stream appears to have added about a mile to its length lakeward, gaining through the off-shore development of barriers which eventually became the shoreline proper; the river deposits account for this prograding shoreline. These earlier formed ridges exercised an influence on the direction of the river, as the development of the highest Warren beach here was sufficient to turn the course of the stream to the west about one-half mile.

It is evident that Black river had a falls over the Berea sandstone a short distance north of the point where the two branches now meet. Since that time the falls have moved up-stream not much over a mile. North of the outcropping Berea the river has had easy work in the shale; it has developed many small tributaries considering the small area drained.

In the region south of Avon Center only one stream, the headwater part of French creek, appeared after the Whittlesey decline; this flowed into the lake near Avon. The drainage from the area north of Butternut Ridge escaped across the Whittlesey beach, thence to the Black river. Different segments of this stream show the directive influence of beach ridges.

West of the Black river the two beaches are so close together that few streams developed save continuations of those that were already tributary to Lake Whittlesey; these were lengthened usually by one mile, the average distance between the two beaches. Beaver creek, however, responded most successfully to the added 60 feet in gradient; south of North Amherst it has made much progress in valley development, considering the resistant rock in which it is working.

Lake Erie base-level.—Lake Warren dropped about 95 feet in establishing this new base-level. The added drainage territory is entirely in shale, with a very slight veneer of glacial drift. This easily eroded rock has given the streams which cross it an appearance of greater age than these same streams show in the much older parts of their course. Both Black river and Beaver creek have developed relatively wide valleys, which they are still broadening by lateral erosion. These two streams control so completely the drainage territory south that the shore of Lake Erie is creased by only a couple of other creeks that have as yet accomplished much erosion. Two slight streams near Beach Park have cut the shales back, developing youthful valleys. West of Black river, Martin run has made a longer and slightly wider valley.

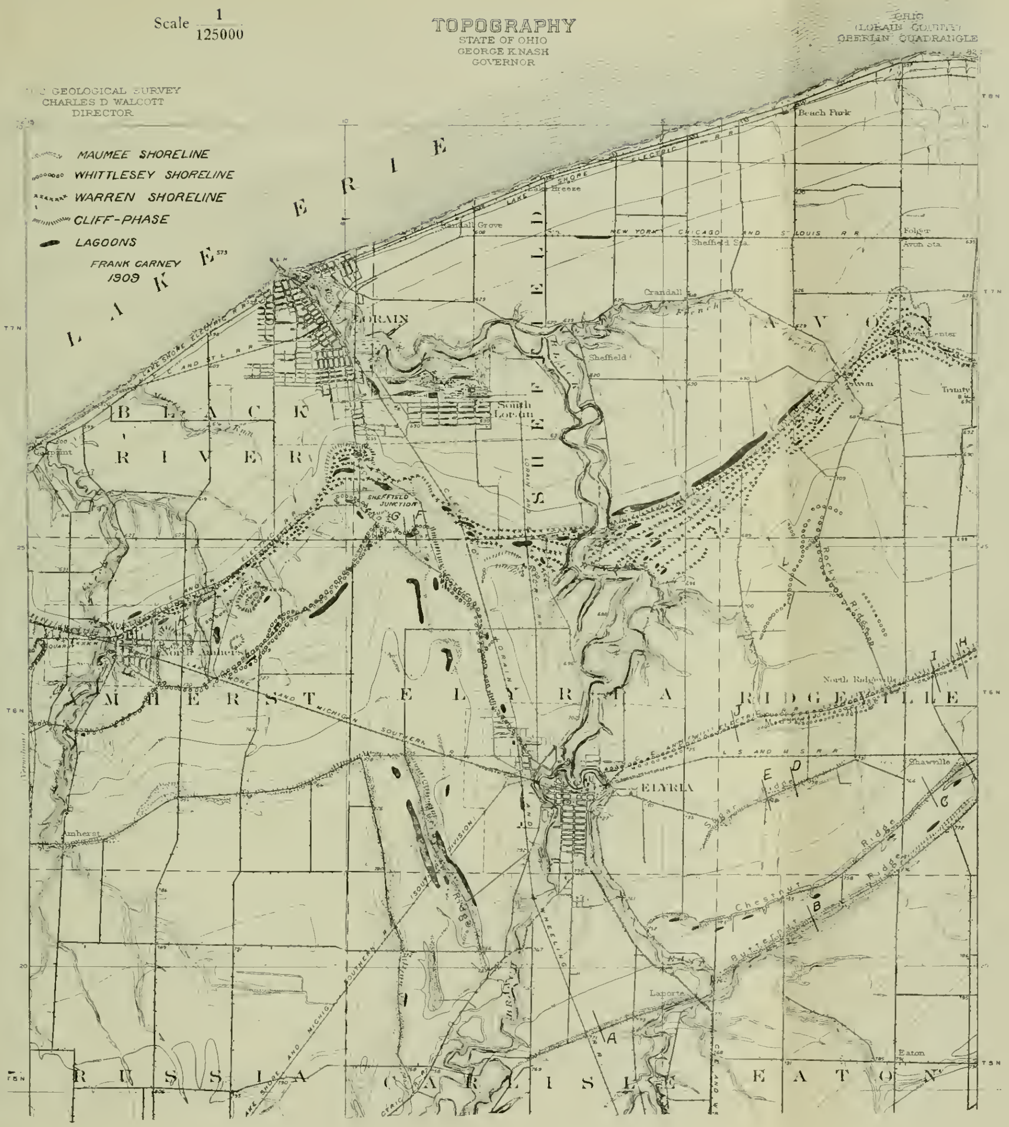
Summary.—In the northern fourteen miles of its course, Black river has been subject to four base-levels. We have no data for satisfactorily measuring their relative time periods. The Berea sandstone, which it crosses at Elyria, forms a local base-level for the river south of this place.

In the last six and one-half miles of its valley, the fall of the river is about seven feet, approximately a foot per mile. North of the Warren shoreline, it discontinued down-cutting long ago; its further work, in reference to the present base-level, will be entirely lateral plantation, the process which has already widened the valley in some places nearly a half mile. When the Lake Erie level was inaugurated, this portion of Black river had a descent of 95 feet.

In the interval of approximately five miles between the Warren and Whittlesey shorelines the initial slope was about 60 feet; the fall of the stream is now about 70 feet; the gain in gradient is a response to the Erie base-level. Much more erosion has been accomplished than would appear to be the case from these figures, as part of the 80 feet of channel-cutting involves the resistant Berea sandstone. The width of the main valley, its numerous tributaries, and their maturing cross-section, show that the Whittlesey part is much older than the Warren part of the river.

In the Maumee section we would expect even greater evidence of age. But here the time factor is offset by the hard rock the river has had to work on; its valley is shallow, and there are few tributaries. South of this highest shoreline, the surface is more creased by stream courses with somewhat wide valleys.

Plate VII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Lake Breeze
Randall Grove
Sheffield Sta.
Folger
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Avon
Trinity
Sheffield Junction
North Amherst
North Ridgeville
Elyria
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4. Standardization of Well Water in the Vicinity of Granville, Ohio. By Lilly Bell Sefton 119

Chapters on the Geography of Ohio. By Frank Carney

5. Transportation 125
6. Economic Mineral Products 137
7. Glaciation in Ohio 183

GRANVILLE, OHIO, DECEMBER, 1910

STANDARDIZATION OF WELL-WATER IN THE VICINITY OF GRANVILLE, OHIO[1]

LILY BELL SEFTON

The last few years have brought an increasing realization, both to scientists and to those entrusted with the sanitary welfare of the public, of the fact that the water supply of a locality has much to do with the health or ill-health of its inhabitants. In consequence, there is scarcely a city of any size that has not done more or less to better its water conditions. Filtration plants are being established, reservoirs are cleaned more frequently and scientifically, while the sale of distilled water has become a most profitable business.

It is unfortunate that this improvement is confined largely to municipal boundaries. What is true of a city with regard to its water supply is just as true of country districts. A contaminated well is as certainly productive of evil results as is a filthy reservoir or a polluted river. Moreover, when we remember that this well furnishes water for cattle, and that the cattle products are marketed in the large cities, it will be evident why these same evil results may be as far-reaching. It is highly important, therefore, that the farmer, as well as the city-dweller, know whether or not the water that he uses is pure. It happens that there is no fixed criterion by which the wells of different localities can be judged. Nearness to, or remoteness from, salt bodies, elevation above sea-level, differences, both chemical and geological, of soil, all combine to make it necessary for each community to have its own standard of purity.

The following analysis was made for the purpose of establishing such a standard for the wells in the Granville vicinity. Twenty samples were analyzed—samples taken from wells within a three or four mile radius of the village. The water was examined for dissolved solids, chlorine, ammonium, both free and combined, nitrates, nitrites, oxygen-consuming power and phosphates; and the analysis was conducted according to a scheme given by Leffman,[2] although it was found necessary to make several modifications of his plan.

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[1] This work was done under the direction of Prof. A. M. Brumback.

Before the actual analysis began, all the reagents and solutions to be used were very carefully prepared and standardized. Just here it may be well to mention one thing, which was learned by hard experience, and without which it will be impossible to secure results in any way satisfactory. It is this: use absolutely ammonium-free (and this, usually, will be also nitrite-free) water in the preparation of all reagents. To secure such water, twenty grams of potassium hydroxide and five-tenths grams of potassium permanganate were dissolved in a liter of ordinary distilled water, and then the solution was re-distilled by means of a Kjeldahl apparatus. The water obtained was used in making up another and stronger solution of the same kind. Two hundred grams of potassium hydroxide and eight grams of potassium permanganate were dissolved in a liter of this water, and fifty cubic centimeters of this solution were added to every liter distilled afterward. Water will remain ammonium-free for only a comparatively short time, so the reagents must be made up immediately.

The water to be tested was collected in two-liter bottles, made of green glass and provided with tightly-fitting stoppers. Since the purpose of this analysis was to establish a standard of purity, samples were not taken from any wells save those thought to be pure. This was determined by ascertaining that the well was not located near, nor in any way connected with, such sources of impurity as barnyards, cesspools, and vaults; by making sure that no sickness had ever been traced to the use of the water; and by finding out how recently and why the well had been cleaned.

Three analyses were carried on at a time. Owing to the variability, from time to time, of the quantities of ammonium, nitrites, nitrates and oxygen-consuming power, these were tested for first, while the tests for chlorine, phosphates, and dissolved solids were left till later.

In testing for ammonium, standards containing a known equivalent of ammonia were nesslerized and then the first three or four distillates (similarly nesslerized) were compared with these. After the free ammonia had been driven off, the remainder of the sample was treated with fifty cubic centimeters of the alkaline permanganate solution, which converts into ammonia certain forms of the nitrogen contained in any organic bodies which may be present in the water. The amount of organic matter is thus indicated, and consequently the purity of the water. Leffman gives .123 parts per million as the highest possible amount of albuminoid ammonia allowable in pure water. It will be noticed that samples 4, 8, 12, and 22 greatly exceed this amount; but, since both 4 and 22 are wells of exceptional depth, it is probable that this is not indicative of impurity in them. Deep wells very often contain harmless ammonium compounds which increase the apparent amount of ammonium. Samples 8 and 12, therefore, come under suspicion. It is worthy of note, also, that in both 4 and 22 the oxygen-consuming power is correspondingly high, showing that the organic matter was of vegetable, and therefore of harmless origin; also that in all four cases the ammonia was given off slowly, indicating a slow decomposition of organic matter, which is not so harmful as a more active decomposition. The fact that in some cases the results obtained by adding the permanganate at once are higher than when the results of the two separate methods are combined, may be due to this—that in the latter case, some of the combined nitrogen is driven off in some other form before the permanganate is added.

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[2] Henry Leffman, *Examination of Water for Sanitary and Technic Purposes*, 1895.

Closely related to ammonia, in its significance, is the presence of nitrites and nitrates. Leffman, in his general standard, says that uncontaminated water shows little if any indication of the presence of nitrites.[3] It will be noted that the results from this analysis run from very faint traces to 1.23 parts per million. Since every sample is assumed to be healthful, we may safely conclude that well-water in the Granville vicinity may have as high as 1.23 parts per million and yet be considered pure.

There is a difference in the opposite direction with nitrates. Leffman allows as high as 1.25 parts per million; none of the samples analyzed, save two, gave more than .5 parts per million. Many of them show but traces. Since in both the exceptions (samples 2 and 10) there is no decided departure in other respects from the average, it may be concluded that these excesses are not suspicious.

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[3] *Ibid.*, p. 93.

Leffman says: "The popular notion that hard waters conduce to the formation of urinary calculi is not borne out either by statistics or by surgical experience. . . . No absolute maximum or minimum can be assigned as the limit of safety."[4] The table below shows that the amounts ran from 28 to 807 parts, the difference being due largely to the difference in the deposits through which the waters have come.

Since chlorides are abundantly distributed in the soil and are in most cases freely soluble, a wide range of amounts may be looked for. But one sample (14) runs higher than 20.12 parts. Phosphates, on the other hand, while just as freely distributed as chlorides, are highly insoluble, so that we may expect, what we really find to be the case in this particular instance, very little, if any traces of phosphates. Both chlorides and phosphates are characteristic of animal excretions, hence an excessive amount of either or both with no apparent reason, is open to suspicion.

Mention has already been made of the oxygen-consuming power. The estimation of this gave much trouble, until absolutely ammonium-free water was finally used as a standard. Each sample and the standard was treated with acidified potassium permanganate and kept at a temperature of 96° C. for three hours. At the end of this time, by titrating with sodium thiosulphate, it was found how much oxygen had been consumed by the organic substances in the water. In but three of the samples was an excessive amount consumed. Samples 4 and 22 have already been satisfactorily accounted for, and sample 10 does not exceed the maximum limit according to Leffman.[5]

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[4] *Ibid.*, p. 92.

[5] *Ibid.*, p. 99.

SAMPLE	DEPTH OF WELL	SOLID MATTER	CHLORINE	FREE AMMONIA	ALBUMINOID AMMONIA	TOTAL BY SEPARATE METHODS	TOTAL N AS NH_3	NITRITES	NITRATES	OXYGEN-CONSUMING POWER	PHOSPHATES
1.	Tap	528.	20.12	.0216	.0432	.0688	.0648	Slight trace	None	.216	Trace
2.	35	325.	18.5	.0456	.078	.1236	.1212	.012	4.	.121	None
3.	Cistern	31.	None	.0204	.0576	.0864	.062	.012	.2	.218	None
4.	187	458.	5.593	.1968	.2486	.4454	.4848	.08	Slight trace	1.872	Trace
5.	14	112.8	5.8002	.0024	.0888	.0912	.0936	Very faint trace	Faint trace	.0862	Medium trace
6.	48	113.2	7.4574	.0144	.1052	.1196	.1150	.33	Faint trace	.211	None
7.	85	171.6	15.74	.0284	.0288	.0572	.0600	Trace	Medium trace	.719	None
8.	28	200.	16.71	.032	.1416	.1736	.1656	.25	No trace	.234	None
9.	65	202.	2.28	.0336	.1128	.1464	.1408	Very faint trace	No trace	.0912	None
10.	25	548.	7.11	.0096	.1008	.1104	.103	.0532	2.	1.23	Trace
11.	30	28.4	6.835	.0144	.0516	.0660	.0672	.0568	Very faint trace	.865	None
12.	28	689.	12.5	.0126	.1416	.1536	.1608	.248	.5	.547	Faint trace
13.	54	466.4	15.12	.0108	.0768	.0876	.0864	.017	.5	1.111	None
14.	20	336.	60.07	.006	.0980	.1040	.1056	.017	.5	.834	None
15.	33	722.	18.71	.0144	.0492	.0636	.0600	Faint trace	Faint trace	.347	Medium trace
16.	125	807.6	10.49	.0252	.0564	.0812	.0816	1.32	Faint trace	.792	Faint trace
17.	35	608.4	9.1146	.0204	.0501	.0748	.0672	Very faint trace	None	.438	Faint trace
18.	32	418.8	6.69	.012	.0384	.0504	.0576	.99	None	.009	None
19.	44	654.	10.426	.012	.0432	.0552	.054	.66	Very faint trace	.918	Medium trace
20.	60	435.	9.735	.0264	.0684	.0948	.1102	.50	.2	.356	Medium trace
21.	32	217.	4.78	.0252	.054	.0792	.0754	.33	Faint trace	.212	None
22.	180	376.	11.24	.036	.246	.282	.2354	.25	None	1.594	None

CHAPTERS ON THE GEOGRAPHY OF OHIO

FRANK CARNEY

With this issue of the BULLETIN I begin the publication of some chapters dealing with the geography of Ohio. The chapters will not appear in the order proper to a unit treatment of the subject, but as particular phases of the study have been completed.

The method of treatment is an attempt at such comprehensiveness as the average public school teacher needs, but usually has neither the time nor the available literature to procure. Useful bibliographies and the necessary maps will be a part of the completed work.

It would be a time-consuming task to particularize my obligations to the literature. There is nothing new in these chapters; many of the facts were acquired from scattered sources at odd times during the last five years, with no thought of thus using them. The various publications of the State Geological Survey have been drawn on freely in discussing the economic mineral products.

To Dr. J. A. Bownocker, State Geologist, I am much indebted for the privilege of quoting from his publications on salt, and on natural gas. Particular acknowledgment is due Dr. George D. Hubbard, Professor of Geology, Oberlin College, for reading the manuscript, and making valuable suggestions.

TRANSPORTATION

Immigration routes.......... 126
Early prosperity.......... 127
Canal construction.......... 128
Railroad building.......... 129
Electric railways.......... 134
Better highways.......... 134

Regardless of its mineral wealth, rich soil, waterfalls for energy, delightful climate, or any other natural advantage, unless a region is easily reached it will make progress slowly. To appreciate this fact we need only to recall some section of the continent where it has long been known that great mineral wealth exists, but not being accessible, it has remained unexploited; other areas have very rich soils, but are still fallow, simply because they are not within easy communication. There is no incentive to mine ores, or to grow crops in excess of immediate requirements, if this excess cannot be marketed.

Ohio occupies a peculiar position in reference to the Atlantic states on the one hand, and the Mississippi valley on the other. Probably 90 per cent of the present-day commerce between these two sections passes through, or along the margin of, Ohio. Ohio is the backdoor of the more densely populated Atlantic states. For a long time, the Appalachians were a formidable barrier; the sea coast strip was easily colonized and largely exploited before colonists moved across the barrier. When congestion compelled expansion into the interior, natural routes were first utilized. The Mohawk lowland is the lowest pass across this barrier; through it pulsed the lines of emigrants, and later the traffic of stage routes, canals, and railroads.

Immigration routes. While to-day we regard the Mohawk lowland as the easiest route to and from the northern coast states, it is a curious fact that the earliest colonists into the trans-Appalachian region came by more rugged routes. The Cumberland pass, and the river-route from the site of Pittsburgh, were first used. The Mohawk pass was itself so inviting an abode and it opened upon such fertile plains in western New York that settlements were established there, before it was necessary to push out farther along Lake Erie. The emigration into northern Ohio is associated rather with political conditions than with this more easy line of traffic. Furthermore, the necessity for expansion arose earlier in the Atlantic states opposite Ohio. The first settlers in Ohio, as well as the first explorers, approached the state by the Ohio River. Peoples enter new regions by river valleys, where they exist; the earliest settlements therefore are valley towns. The first clearings for cultivation are usually made on flood plains. With the increase of population, lands are cleared in higher altitudes. This is a matter of convenience; river valleys afford natural grades for traffic, where it is carried on wheels, and the river itself welcomes boats. But in studying the location of first settlements in some parts of the state, we find that this rule does not always hold. Some settlers chose the hilly regions even when the level lowlands might have been had. Whenever such a choice is made, it usually reflects a previous topographic environment of the settlers. Men reared among hills, when coming into new areas, select similar topography. From the Ohio river, extending far north through the state, are several important river valleys; the earliest towns were founded along these rivers.

Early prosperity. Commonwealths have to learn how to accumulate wealth. A state may have an ample rural population, and yet have no particular rank among commonwealths. Its property may be owned by individuals and be unencumbered. Indebtedness may be generally abhorred by its citizens, and yet among states it may be counted very backward. For a state to be effectively prosperous, its citizens must accumulate more than their homes and farms. It is the excess wealth that counts. Ohio has always been an agricultural state. In its early history, farmers had to be contented with growing enough to support their families and slowly accumulating money to pay for their homes. There was only one way in this early period for them to acquire much more than this. It was quite impossible to reach larger markets, because there were no facilities of transportation. Hence there was little to be sold for cash. The simple needs were usually met by barter. This condition did not apply so stringently in the parts immediately adjacent to the Ohio and its larger tributaries, but this was only a small portion of the state.

Farmers learned early that the easiest way to secure cash was to raise cattle which could be herded and driven to larger markets. In consequence, the first important position attained by any center of population in this state came through slaughtering and meat-packing. Cincinnati, for many decades the metropolis of Ohio, was also for many decades the center of the slaughtering industry in this country. Eventually the central and southwestern part of the state began to accumulate capital through the pasturing of cattle and feeding of hogs; while a wealthy aristocracy of middle men was developed in Cincinnati. A European traveler,[1] who visited Cincinnati in the early forties, alludes in his report to the "Pork Aristocracy" of that city. But Ohio made no great progress in the acquirement of wealth till ready lines of communication with the east were established. This came first through the construction of canals.

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[1] Sir Charles Lyell, *Travels in North America*, New York, 1845.

Canal construction. The canal-digging fever struck Ohio shortly after its outbreak in the Atlantic states. In 1817 its legislature considered the matter of constructing waterways; the subject came up regularly in the following years, culminating in 1825 in a law that commenced operations. In this same year Clinton's "ditch" tapped Lake Erie. The Ohioans, therefore, did not wait for positive proof of the advantages of improved waterways. The evidence was forthcoming, had it been necessary, for immediately after the Erie Canal had wedded the lake and the ocean northern Ohio felt a new throb of commercial life. Lake trade was stimulated, harbors were improved, wharves and warehouses constructed; and prices advanced on all commodities that could be conveniently reached. The Ohio legislature had taken the initiative without these evidences. In seven years the Ohio Canal, 360 miles long, was completed, connecting Portsmouth on the river, at the mouth of the Scioto, with Cleveland on the lake. The Miami Canal, joining Cincinnati and Toledo, was commenced in the same year, reached Dayton in 1830, but was not completed to the lake till 1845. Along either canal route trade activity shortly developed the sleepy villages into thrifty towns and cities. Later adjustments have left some of these places only a retrospect; the canal period was their heyday. Others, however, as for instance Newark, Coshocton, Massillon, Akron, Hamilton, Troy and Defiance, have continued to prosper under the conditions incident to the transfer of shipping from the canals to railroads.

The Ohio Canal, the course of which was controlled by other considerations than merely joining the river and the lake, makes an ascent of almost 500 feet. Its construction, relative to its length, was much more expensive than the Erie Canal, which ascends only 445 feet. The maintenance of the Ohio Canal also involved greater expense. For this reason, with the extension of railroad lines in the state, we find that by 1856 the canals of Ohio ceased to earn running expenses. During about twenty years, however, these canals were of great commercial importance to the contiguous parts of the state. Even upon the opening of the canal from Dresden to Cleveland, the price of wheat advanced from 25 cents to $1.00 per bushel.[2]

Railroad building. These canals had barely been completed before Americans started earnestly to building railroads. The construction of canals was always expensive, and the country accommodated by them necessarily limited; relatively, the freight rates were cheap, but on account of slowness of transportation many crops could not be shipped. Some of the canals naturally were neglected; and the state's energy was given to building railroads.

When we speak of railroads to-day, we at once think of one or another of the great "through lines." In the early days of railroad construction, no one dreamed of even a trans-state road. Until recent years a through line always meant the consolidation of short independently owned segments. Local interest in railroad building in Ohio was lively from the start. Thrifty commercial relations emphasized the inadequacy of boating facilities. The efficiency of the Lake Erie and Erie Canal route was not questioned, but there were few canals in Ohio to give access to the lake. The first steam road to operate in the state (1836) had one terminus on the lake at Toledo, the other being at Adrian, Mich. Sandusky had no canal, but by 1839 it completed several miles of a railroad, "The Mad River and Lake Erie," towards Dayton, which point it reached in 1844. Ohio capital and enthusiasm for railway construction were abundant, as shown by the fact that in 1837 forty-three railroad companies were organized by state charters. Many of these roads were never built, but some of them have become the best lines in the state. By 1846 a road was completed from Cincinnati to Springfield, and, by 1848, through steam connection was made between Cincinnati and Sandusky. Columbus and Cleveland were connected in 1851, and during the same year a railroad was finished between Cleveland and Cincinnati. The next year a line was opened from Cleveland to Pittsburg.

Geographically, Ohio needed transverse railroads; the lake and the river were its natural thoroughfares to markets; the wide, fertile major valleys of the state trend north-south, and its products move almost by gravity to one outlet or the other.

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[2] Henry Howe, *Historical Collection of Ohio,* vol. ii (1891), p. 325.

Ohioans, except the immigrant ancestors, never gave further thought to the "Appalachian barrier;" their commercial friends on the seaboard looked after building the east-west lines.

The rivalry of the Atlantic ports in establishing through railroad transportation to the Mississippi basin was thus an advantage to Ohio. The Hudson-Mohawk valley made the construction of a line a child's task for New York, but the Appalachians imposed on Baltimore and Philadelphia a herculean undertaking; the former city early recognized the limitations of canals. A citizen of Baltimore, in urging the undertaking, said:

> Baltimore lies two hundred miles nearer to the navigable waters of the west than New York, and about one hundred miles nearer to them than Philadelphia; to which may be added the important fact, that the easiest and by far the most practicable route through the ridge of mountains, which divides the Atlantic from the western waters, is along the depression formed by the Potomac in its passage through them.[3]

In 1828 construction was commenced at Baltimore on a line headed for the Ohio valley, but twenty-five years elapsed before this destination was reached by the Baltimore and Ohio Railroad, the difficulties of construction having been underestimated. The next year, 1854, the Pennsylvania line reached Pittsburg, with which city Cleveland had been joined the preceding year. In 1852 a road was opened from Buffalo to Cleveland; the same year, one from Toledo to Chicago; and the next year through traffic was made possible from Buffalo to Chicago. In 1857 a road across southern Ohio and on to St. Louis was completed; this was practically a continuation of the Baltimore and Ohio Railroad. By 1860 Ohio had what was considered in that day very ample railway facilities, a condition which contributed largely to the position that the state at once took in manufacturing.

When men were first building railroads, the matter of dividends was not as carefully thought out as nowadays. Knowledge came with experience. Usually the railroad fever struck a section of the state, and a railroad was built somewhere. More often than otherwise, bankruptcy closed the venture. Each road, built in the last two decades at least, shows that it was to meet already existing demands for freight hauling and transportation, or else that these demands were so obvious as to be realized at once on the completion of the road. Usually objective points existed, which the road entered. These were the "through lines" from which, to other objective points, branch roads were constructed.

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[3] Philip E. Thomas, quoted in Johns Hopkins University *Studies in Historical and Political Science, Third Series* (1885), p. 99.

The objective points, however, of these through lines are not always cities but more often regions, the business of which focuses in a city. It is fortunate for Ohio that its position necessitated roads being built through it, that they might connect these larger objective points. We have already learned that a few short segments, built by local capital, were incorporated into some of these through lines; but Ohio's money went rather for building roads transverse to these, acting as outlets and feeders for communities away from the larger roads. At these junction points were developed "railroad towns;" here were the railroad shops and homes for the men employed by the road. Later, if more roads passed across the same community, it became a "railroad center."

The presence of these roads usually inspired rapid growth, and a city in time developed. It appears, therefore, that the primary reason for the location of our larger railroad lines is not found in human activities along its route preceding the railroad. The course of the railroads was determined by the cost of constructing road beds; in parts of the state there were some deep gorges and valleys to be bridged. The route was to some extent a matter of topography. If the towns were in the way or could be reached without serious change in the route, they were passed through, but ordinarily the road was not being built for these towns. Later, as the result of the railroad, many such communities became populous centers; manufactories were built; distribution points for goods from the outside were established; warehouses, and storehouses for shipping of local products were constructed. Thus, in a few decades, a railroad, that was built through a region of scattered population, leads from city to city. Later other roads are built to these same centers, but not for the same reason that the initial road was constructed; secondary reasons have become active. These other roads represent capital that desires profitable employment.

Here are two cities, already busy places, but on separate "through" roads. Naturally business is carried on between the two centers. This could be done with greater facility if there were a connecting road. The road is built with profit. Again, one of these cities uses much coal for manufacturing. In another part of the state are mines in operation, which could produce far more coal if there were a greater market. That city is now getting its coal by a circuitous route from another coal-producing region. Capital sees profit in connecting the former mines with that city, and a road is built. Railroads have also been constructed largely for supplying an outlet to a large farm region; some secondary reason may have been present, but, operating with this immediate secondary reason, there is always the hope that the roads built will inspire development along their routes, which will insure still greater profit. Furthermore, some roads are built solely for hauling coal, others for hauling ore. The former, more often, are spurs or branch lines from railroads already in operation. As illustrative of the latter, reference should be made to the Lake Erie and Pittsburgh route, connecting the city of Cleveland with Pittsburgh. Iron ore is brought down the lakes cheaply, and unloaded at one of several ports in northern Ohio. The reduction plants of Pittsburgh and elsewhere along the upper Ohio River are dependent now on Lake Superior ore. These plants have coal near at hand. Some of them were constructed when ore in that immediate part of the country was being mined plentifully; then they had both the ore and the coal; now they have to get the ore from a distance. The cost of landing the ore at a lake port is not great, but it is expensive to haul this ore across Ohio, and the expense of transportation is dependent to a great extent on the grade of the road bed. Therefore, this road, recently constructed, has been located with but one end in view, that is, to obtain the lowest possible percent of grade. The expense involved in making cuts or in building bridges appears not to have been considered. A low grade, regardless of other factors of location, apparently determined the route.

When we consider the increasing number of blast furnaces appearing along Lake Erie, we naturally wonder what will eventually be the outcome of the competition between the old centers of ore-reduction and the lake front.

A railroad map of Ohio to-day is indeed a network. This pattern is due to the development of numerous railroad centers. Cincinnati, Dayton, Springfield, Columbus, Marion, Lima, Toledo, Akron and Cleveland are focal points of many roads. These places lie north and west of the irregular topography of that part of the state where the Pennsylvanian formations outcrop. While, relatively, this part of the state has no high altitudes, at the same time, it does form something of a barrier between the lowland of the Ohio River and the lake plain on the opposite side. Most of the roads which cross this high area follow natural depressions made by river valleys. These routes were cheaper from the standpoint of railroad construction, and they pass through towns that give business.

The gross railroad mileage in Ohio in 1908, including electric lines, was 14,471.43. This gives an average of 0.352+ miles for every square mile of area. The following table shows how we compare with other states of the Mississippi valley in both the gross mileage of steam railways and the miles per square mile of area.

	AREA	MILEAGE	PER SQUARE MILE
Ohio[4]	41,060	9,111.27	0.221+
Indiana[5]	36,354	7,326	0.202+
Illinois[5]	56,665	12,796	0.218
Missouri[5]	69,420	8,141	0.117+
Nebraska[5]	77,520	6,083	0.077+
Iowa[5]	56,147	9,865	0.178+

There are still some sections of the state that are not convenient to railroad routes. These lie mostly within the area of the "Coal Measures." More roads are bound to be built in these parts. The coal deposits in time will be worked, if not for distant shipping, at least for local manufacturers. As the population of the state increases, the present neglected rougher areas will be occupied, and grazing or agriculture will be developed. This should also occasion railroad building in these parts. Furthermore, still more roads will probably be constructed between the lake ports and the Ohio valley steel centers. I believe, however, that in time the number of steel plants along the lake front will increase at the expense of those in the Ohio valley. Well established industries die slowly. It is cheaper to haul coke to the lake than to carry ore from the lake to the older plants. Topography is a silent partner in industry; it never goes bankrupt.

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[4] *Annual Report Ohio Railway Commission*, 1908, p. 402.

[5] *Railway Statistics of the United States of America for 1908*, p. 21.

Electric railways. The last decade has witnessed in Ohio a new phase of transportation. Trolley lines were first built in cities for passenger service. Then urban extensions were made. Gradually these grew longer. The urban lines of cities not widely separated met each other. Other places were then purposefully joined. Electric lines were built between still more distant centers. Now one speaks of "through" electric routes as we formerly did of "through" steam railways. Traction lines no longer depend entirely upon passenger service for income. They have taken on freight and express business, not only with profit to the investor, but with great convenience to the localities served.

No service of capital in modern times is doing so much to make living in the country more convenient. It is too early yet even to classify the changes of modern business methods, due to electric lines that are gradually extending over the state. These routes are encouraging more profitable phases of agriculture. They afford prompt service, making it possible to market perishable crops; and the centers of population thus served are equally benefited.

Better highways. Nowadays we hear much about highway improvement. Our legislatures, for a few years, have been making annual appropriations for the betterment of highways. Municipalities have been taxing themselves, that they might improve the roads leading into their immediate rural sections. Long ago it was the opinion of statesmen that the federal government should do this kind of work. The National Road which crosses this state is a product of that feeling. In the year 1811, this road was started from Cumberland, Md.; by 1818, it was completed to Wheeling, W. Va.[7] A dispute arising as to the constitutionality of the government's undertaking, the construction of the road was suspended till 1825; then an act was passed, making an appropriation for its extension to Zanesville. From Wheeling to Zanesville, a thoroughfare had long been in use; this had been authorized by an act of Congress in 1796, for the benefit of early settlers in Kentucky and the southwestern part of Ohio, whose journeys eastward through Pennsylvania were frequent, but very difficult either by the up-stream river route, or by the old "Wilderness Road." West of Wheeling, the National Road followed this highway, called "Zane's Trace," to Zanesville. By 1833, the National Road reached Columbus. Without much delay it was continued through Springfield into Indiana.

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[7] Ohio Archeological and Historical Society Pub., vol. ix (1901), p. 435.

I suppose the Roman roads and later road-building of European countries furnished the suggestion for this undertaking by our government. The advantages of the national road were never questioned; but the fact that the original plan, to carry it through to St. Louis, was not accomplished may imply that the returns were considered inadequate for the investment. It is unfortunate that a people, which early recognized the advantages of good highways, should have forgotten them as soon as they commenced to build canals and railroads. Only in recent years have we come again to recognize the advantages of cheapening the cost of natural products by making less expensive the first part of the haul to markets.

In Ohio we have much valuable limestone. We have no crystalline rocks, except the "nigger heads," the material that is used so extensively for roadbeds in New England. But with our limestone, and selected sandy lime formations, it should be possible to make durable roads. I have noted that most communities are startled at the great expense of building even the cheaper roads. It is felt that large sums are required for the kind of roads being constructed. Another generation may justly accuse us of squandering it. It is far cheaper to spend double the amount which is being put into some of our highway improvements, thus getting a roadbed that with a slight annual expenditure would endure for generations. It is unfortunate that Americans cannot look at the matter of building highways as do some European states.

THE ECONOMIC MINERAL PRODUCTS OF OHIO

Introduction 138
Iron 139
    Early furnaces
    Early methods
    Products
    Decline of the industry

Building stones 143
    Important properties
    Limestone
    Sandstone
    Flagging stone
    Other quarry products

Salt 148
    Early development
    Geological relations
    Origin of salt

Glass Sand 153
    Sources
    Preparation for market

Other sands 154
    Moulding, building, engine, furnace

Lime 155
    Uses; sand-lime brick

Cements 156
    Natural, pozzuolane, Portland

Abrasives 157
    Natural, artificial

Natural gas 158
    Early history
    Pre-commercial use
    Commercial exploitation
    Conservation

Oil 162
    Early history
    Washington, Noble, Trumbull, Morgan, Wood counties
    In other counties
    The handicap of early wells

Stratigraphy of oil and gas 165
Ordovician, Silurian, Devonian
Mississippian, Pennsylvanian
Occurrence in rock
Origin of oil and gas 167
The inorganic theory
The organic theory
Production of oil and gas 169
Natural gas
Petroleum
Clay 170
Properties of clay
Kinds of clay in Ohio
Rank of state
Coal 173
Pennsylvanian rocks of Ohio
Methods of mining
Centers of coal mining
Geography of Ohio in the Pennsylvanian period
The origin of coal
Kinds of coal
Rank of state in coal production

INTRODUCTION

Agriculture alone can give a commonwealth a high position. But the crop-producing capacity of a soil is in no wise diminished by the fact that mineral wealth may underlie the area. Agricultural states, having mineral wealth, are thereby the richer. Early in its history, Ohio took a foremost position in the production of minerals. While its rank in reference to particular minerals has shown great change, it still outranks other states in some valuable products. The earliest explorations in Ohio appear not to have had for an object the discovery of minerals. The first settlers came into the state to establish farm homes, and the early exploitation of its minerals was made to satisfy local demands that could not very well be met otherwise. The iron ores were worked at first to supply the needs of households and farms. For this reason the iron mines in Ohio were of great importance during its early decades.

IRON

Three classes of iron ore have been worked for this mineral in the state. The most conveniently handled of all perhaps was that obtained from bogs, though a furnace for reducing this kind of ore was not erected until 1824. Nearly all the bog ore furnaces were built in the northern part of the state near the shorelines of the ice-front lakes. The ore is thought to have been deposited by spring water which combined chemically with certain organic products of bogs, making a precipitate of iron. This source of iron never proved very profitable, consequently it was not able to compete with other ores.

In connection with certain clastic beds of the lower Pennsylvania formations, many iron stone concretions occur. These appear to be nodular clay products in which the iron has been assembled; possibly the iron concentrates made the concretions. Through the weathering of these horizons the matrix rock is more easily disintegrated; the concretions endure, and are found along slopes and stream courses. The earliest furnaces using this ore gathered their supply chiefly from valley bottoms. The supply being limited, these furnaces did not continue long in operation.

The most valuable iron ore that has been worked in Ohio is a limonite, first found as pockets or depressions on the upper surface of the Niagara limestone; sometimes many tons of ore were removed from a single body. The second blast furnace built in the state, along Brush Creek, in Adams County, used these ores. Other furnaces were shortly put up in the same area. Later they ceased to be profitable, because of the higher grade ore found in the Hanging Rock region of Lawrence County. This was also a limonite, but instead of occurring in pockets, it existed as continuous beds at several horizons in the lower Pennsylvanian formations. The Hanging Rock limonite is a weathered carbonate of iron. In weathering, the iron is hydrated by the action of ground water or of the atmosphere. These beds bear limonite for some distance below their outcrops, but blend gradually into the unaltered carbonate ore.

Early furnaces. The first blast furnace in this state was founded in 1806 at Poland, in Mahoning County, and commenced making iron in 1808. This furnace used the nodular clay iron-stone of the coal measures. The second furnace, built at Niles, in Trumbull County, began operations in 1809. Within a few years numerous furnaces were erected in the ore-bearing regions. All of these had a precarious existence; many of them were operated intermittently, changing ownership frequently. The supply of the ore sometimes gave out and sometimes it produced an inferior iron.

Not until 1826 was the iron reduction industry in the state of Ohio put on a firm basis. In this year the Union Furnace was built in Lawrence County. The carbonate ores of the Hanging Rock region have proved the most valuable of any we have. This area shortly became the center of the iron mining and reduction industry in the state. The following table, prepared by Prof. N. W. Lord,[1] gives some statistics showing the development of blast furnaces in Ohio:

WHEN BUILT	NAME AND LOCATION	BUILDERS OR OWNERS	ABANDONED
1808	Yellow Creek Furnace, Mahoning Co	Clendenin, McKay and Montgomery	
1809	Mosquito Creek Forge, Niles, Trumbull Co.	James Heaton	1845
1811	Brush Creek Furnace, Adams Co		1826
1812	Mosquito Creek Furnace, Niles, Trumbull Co.	James Heaton	1857
1813	Yellow Creek Falls Furnace, Mahoning Co.	Daniel Eaton and Sons	1833
1816	Middlebury Furnace, Summit Co	Aaron Norton	1842
1816	Brush Creek Furnace, Adams Co		1826
1816	Marble Furnace, Adams Co		1826
1816	Mary Ann Furnace, Licking Co	Owned by Dille B. Moore	
1816	Little Cuyahoga Forge	Asaph Whittlesey	1850
1824	Geauga Furnace, Painsville	Used bog ore	
1825	Concord Furnace, Concord, Lake Co	Burned down	
1825	Railroad Furnace, Perry, Cuyahoga Co	Thorndyke and Drury	1833
1825	Arcole Furnace, Madison, Lake Co	Root and Wheeler (bog ore).	1851
1826	Union Furnace, Lawrence Co	Sparks, Means and Fair.	1854
1823	Franklin Furnace, Franklin P.O., Scioto Co.	James F. and Oran B. Gould	
1828	Junior Furnace, Junior P.O., Scioto Co	Gliddin, Murfin and Co	
1830	Fairfield Furnace, Fairfield, Tuscarawas Co.	Owned by Zoar Community	
1830	Tuscarawas Furnace, Fairfield, Tuscarawas Co	Christmas Hazlitt and Co.	1846
1832	Arcole Furnace, Madison, Lake Co	Wilkeson and Co. (bog ore).	1851

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[1] *Geological Survey of Ohio*, vol v, (1884), p. 450. I use the table only up to the year 1840.

1832	Clyde Furnace, Madison, Lake Co	Clyde Co	1838
1832	Elyria Furnace, Elyria, Lorain Co	Herman Ely (bog ore)	1835
1832	Conneaut Furnace, Conneaut, Ashtabula Co.	Bog ore	
1832	Elyria Forge, Elyria, Lorain Co	Norton and Barnum	
1834	Dover Furnace, Dover, Cuyahoga Co.	Cuyahoga Steam Furnace Co. (bog ore)	
1834	Vermillion Furnace, Florence, Huron Co	Geauga Iron Co. (bog ore)	1840
1835	Mill Creek Furnace, Youngstown, Mahoning Co	Owned by Dan Grier	1850
1835	Middleburgh Furnace, Berea, Cuyahoga Co.	D. Griffiths and Co	1850
1836	La Grange Furnace, Ironton, Lawrence Co.	Ohio Iron and Coal Co	1856
1840	Akron Furnace, Akron, Summit Co	Ford, Tod and Rhodes	1855

Early methods. For several decades the reduction of iron ore depended upon charcoal; limestone for flux was abundant in the neighborhood of most furnaces. The heavily forested areas supplied timber for making charcoal; in some parts of the state the forests were removed anyhow to make way for farms. In the rougher sections of the state, the deforested lands were of little or no account. The use of charcoal in reducing iron ores has always been expensive, if one has consideration for future generations. It has been estimated that to run one blast furnace a year requires 13,000 cords of wood, which represents the timber of 325 to 350 acres.[2] Another estimate shows that to furnish a constant supply for one blast furnace, from four thousand to five thousand acres of woodland is necessary. Even this, to insure a stable supply, would necessitate taking much care of the second growth. The expensiveness of this process appealed to early workers. Mr. C. Briggs, an assistant geologist of our first survey, in 1838, in connection with his report on the iron ores, commented on the preservation of our forests.[3]

It became evident early that the supply of wood for charcoal would give out, thus putting an end to the reduction of the iron ores. Many of these furnaces were in the neighborhood of coal veins but the raw coal had not been tried. Necessity, however, forced a furnace owner either to abandon his plant or to experiment on this possible fuel. Consequently in August, 1846, at Lowville, in Mahoning County, "rock coal," as it was called, was first used in the raw condition in this state. It proved fairly

[2] *Ibid.*, p. 483.

[3] *Geological Survey of the State of Ohio, First Annual Rep.* (1838), p. 93.

satisfactory. Only one other furnace in this country had anticipated this use of raw bituminous coal; the Clay Furnace at Clarksville, Mercer County, Pennsylvania, had used it the summer before. Even after experiment had demonstrated that raw coal would answer the purpose in blast furnaces, it was a long time before the majority of plants discontinued the use of charcoal. In many sections they were already cutting the second-growth forests, and in some localities furnaces had insisted on using charcoal, with the result that the woodlands had been cut for the third time. On a small scale, coal was being coked for a blast furnace at Akron in 1837.[4] I have not been able to ascertain how long coke had been in use.

Products. I have already shown how local necessity led first to the reduction of iron ores. In many cases the molten iron was cast directly from the furnaces into the molds of cooking utensils, stoves, etc. Other uses were soon discovered; charcoal forges were built usually in close proximity to the blast furnaces. These forges turned out malleable or bar iron. Shortly after this, rolling mills and foundries were built at points more distant from the mines. The charcoal pig iron from the Hanging Rock region in particular early obtained a wide reputation. It was shipped to distant points, and had an extensive use at Pittsburgh for manufacturing government ordnance, and later for car wheels.

Decline of industry. By 1856 Lake Superior ores were commencing to be shipped regularly into the northern part of the state. This ore contains a much higher percentage of iron than our native ores. Consequently the furnaces so situated as to conveniently secure the Superior ore gave up entirely the use of the local supply; and other furnaces were put out of business by the competition. The use of Lake Superior ore spread southward through the state, until eventually the native ores were reduced only in the Hanging Rock and Ironton regions. Among the iron-ore producing states in 1907, Ohio ranked seventeenth, supplying but five per cent of the bulk and three per cent of the value of the country's output.

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[4] *Geological Survey of the State of Ohio,* First Ann. Rep., p. 18, 1838.

BUILDING STONES

Not all rock, not even all that appears durable when first quarried, makes a suitable building stone. Neither is it true that for building purposes the best stone is always used. Quite as important a factor as durability, ease of working and appearance, is the convenience of getting stone to market. Many important quarries have been put out of business by the opening of others which were more available. In building stone production, Ohio has maintained an important position for many decades. Stone from its quarries has been shipped to all of the central Atlantic states, as well as into the Mississippi basin states.

Important properties. A stone must be strong enough to sustain the weight to which it is subject in a building. This property is termed "crushing strength," which refers to the number of pounds pressure per square inch required to break the stone. Few stones, however, have been found unequal to any ordinary weight which they would be called upon to sustain in regular building processes. Even a structure like the Washington Monument imposes on the stone of its base a weight of only a little above six thousand pounds per square inch. The crushing strength of average sandstone runs from six thousand to thirteen thousand pounds. The finer grained limestones frequently have a much higher crushing strength. In reference to this property, the highest grade stones are the granites and crystalline igneous rocks of which we have no quarries.

For many purposes, it is very necessary that a stone be hard, or else become hard when exposed in buildings. Certain sandstones may be crumbled even with the fingers. The particles of sand, being quartz, are themselves very hard, but the "hardness" of a clastic rock depends upon the manner in which its components are cemented together. It is quite immaterial how hard the individual particles are, unless they are firmly knit together the stone will not be hard. The usual cements are lime, silica, and iron. The more common cement of sandstone is silica; sometimes, however, we find both iron and lime. In many sandstones, a trace of iron tends to discolor the stone.

While a stone may be hard, because its particles are closely cemented, at the same time it may be coarse-grained or fine-grained, depending upon its "texture." Furthermore a rock stratum may vary in texture, thus making it uneven. An even fine textured rock is easily dressed and lasts longer. Its texture has had much to do in giving the Berea sandstone of many of our quarries so wide a reputation.

In general, the more durable building stones are those of highest specific gravity or "density." A porous stone naturally is more exposed to the weather. It absorbs moisture which in the winter season freezes and injures the stone. Other things being equal, the best building stone has a fairly high specific gravity.

Clastic rocks, to which class much of our building stones belong, represent the assembled components of older rocks. Under some conditions, small crystals may be developed in these clastic rocks. Usually, however, they are simply an agglomeration of worn particles of earlier rocks. Since minerals among themselves differ widely in color, it follows that clastic rocks also are varicolored. Quartz, for example, is sometimes perfectly white, sometimes red. Feldspar is often red. Most of the biotite is dark. As a result, building stones vary in color, from prevailingly dark to buff and white. Sometimes upon exposure the color of the stone changes. This not infrequently occurs with sandstone carrying a small amount of ferruginous matter which oxidizes and gives the stone a rusty appearance. In walls of buildings, one block of such a stone frequently discolors quite a strip below it.

Limestone. The earliest building stone quarries in Ohio were opened in limestone horizons. Many of our limestones are admirably adapted to structural purposes. The depression of the Scioto valley, and the erosion that has taken place along the axis of the Cincinnati anticline, have combined to expose four ages of limestone, each of which has been used extensively for structural work. I will speak briefly of these four horizons, commencing with the earliest.

Above the Trenton formation, a very hard limestone occurs in the Hudson River group of the lower Silurian. This limestone is found usually in thin beds, quite uniform in thickness. The strata are generally separated by shale layers, which makes quarrying easy, but produces large waste piles. This limestone has had extensive local uses, but has never been shipped to very distant points. Its color and its crystalline surface make it desirable; while it is a little more difficult in dressing, at the same time when properly tooled it is a very pretty building stone. Doubtless the demand will increase as shipping facilities improve.

In the lower part of the Niagara formations, splendid stone for building purposes is found. This stone cuts well, particularly the Dayton phase which is quarried extensively in Montgomery, Miami, Clark, Greene, and Clinton counties, and to some extent elsewhere in the southwestern part of the state. In all of these districts many elegant buildings are made of the Dayton stone.

The Monroe formation of the lower Helderberg supplies a good stone, the "Springfield" stone, especially from the upper part of the formation. While this is quarried at several points, the principal workings are at Greenfield in Highland County, and Bellefontaine in Logan County. This formation is used extensively for crushed stone in road-making.

The Columbus formation of the Devonian furnishes more building stone than any other limestone horizon of the state; the Delaware formation is also used; in the lower beds of each is found stone of the best quality. Extensive quarrying operations in these horizons are carried on at Kelly's Island, Marblehead, Marion, Delaware, and Columbus.

Sandstone. The early reputation of Ohio outside of the state, as a source of building stone, came through its sandstone quarries. The oldest period which contains this form of clastic rock in suitable condition for structural purposes, in the state, is the Mississippian; the Berea formation is the most extensively used. This stone has a color, a texture, and an ease of working, that account for its popularity. It is a very durable stone, and in general holds the original color, or changes color uniformly under exposure. In the early days the Berea workings were developed near growing towns. Even the outcropping edges of the beds, which had weathered into loose blocks, were worked roughly and carted miles into Cleveland. Some farmers made a business of supplying local demands, and did the hauling during the season when the farm work was slack. Later regular quarrying operations were begun; teams and oxen were still used for transporting the stone. With the appearance of railroads and the opening of the new quarries adjacent, the old ones gradually lost trade.

The Berea formation comes to the surface in a general north-south strip through the state. In the vicinity of Cleveland its outcrop trends slightly to the southwest, and then directly towards the Ohio river. At Cleveland, Berea, West View, Columbia Station, Grafton, Amherst and Berlin Heights are found the principal quarries now in operation. Formerly there were several other openings, some of which were worked at a very slight profit, and a great deal of needless competition prevailed. The Cleveland Stone Company is a combination of many owners. With this combination, better quarrying methods have been introduced, and only the openings in good quality of stone were retained. There is no question but that more modern business methods have been used to the advantage of builders, though many quarries have had to go out of business. The stone is put on the market in better shape, and probably of more uniform quality.

The Berea formation affords an exhaustless supply of desirable building stone. The quarries now in operation show a variation in thickness of good quality of stone from 20 to over 100 feet. The deepest quarry is at South Amherst. The oldest are those about Berea. Many of these quarries furnish stone well adapted to abrasive purposes, a use which I described in another section (p. 156).

Several formations, other than the Berea, also supply good sandstone for structural uses. Only a little younger than the Berea is the Cuyahoga, which in the central part of the state embraces clastic beds of sufficient thickness and uniformity of texture to make a good building stone. In general, however, the Cuyahoga contains such thin and irregular beds that the quarries in it are not numerous. Belonging to the upper part of the Mississippian period, the Black Hand formation locally has many quarries. The Black Hand belt, which contains stones suitable for building purposes, extends north-south through several counties. This formation is much more irregular in texture, hardness, and structure than the Berea. It varies all the way from a coarse conglomerate to an argillaceous sandstone. Usually, too, it carries a higher content of ferruginous cement. In the earlier days some quarries of the Black Hand formation acquired much reputation; the Lake Erie and Ohio River Canal passes across its outcrop, and quarries were opened in it for making locks. The early railroads through the central part of the state likewise distributed building stone from Black Hand to more distant points.

In the lower formations of the Pennsylvanian period are some sandy horizons, in which building stone of average quality is found. The best, perhaps, occurs in the Sharon phase of the Pottsville. This outcrops in a band usually parallel to the Black Hand outcrop. All these formations dip to the east and south; thus they appear as shingles over one another. To some extent, sandstone has been quarried from formations higher up in the Pennsylvanian, but so far as I know, only for local use.

Flagging stone. This use, perhaps, may as well be mentioned in connection with building stones. Decades ago, certain quarries in the northern and north-eastern parts of the state had a wide reputation for the high grade of flagging stones furnished. Shipments were made to distant points. These quarries contained beds thin enough and strong enough to cut up into right sizes to be laid directly for walks. Sometimes the uniform thickness of these beds and the absence of joints made it possible to remove slabs of marvelous size. There is record of one slab 5 feet wide, 3 inches thick, and 150 feet long, having been taken out of a quarry near Warren, Trumbull County.[5] In general, however, the beds were so irregular in thickness that much selecting had to be done in matching up slabs for walks. After the stone saw came into use these quarries ceased to be profitable. By the use of the saw, heavy beds of the Berea are divided into slabs of uniform thickness. In connection with several of the quarries now in operation, sawing is carried on many months of each year. The demand for stone flagging is still active, but, recent development in the use of cement promises that before many years the cement will occupy the field entirely.

Other quarry products. In *Mineral Resources* for 1908 it is noted that Ohio ranks second in its output of crushed stone,[6] and first in crushed limestone.[7] With the promise of greater activity in highway improvement, there will be an increasing demand for our limestones; this state has practically exhaustless calcareous formations, easily quarried and marketed. In the production of curbing stone, we rank second, and hold the same place in flagging. In both of these products, however, it must be expected that the market will decrease as cement comes more generally into use.

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[5] *Geological Survey of Ohio*, vol. v, (1884), p. 580.

[6] *U. S. Geological Survey*, "Mineral Resources," 1908, p. 544.

[7] *Ibid.*, p. 575.

SALT

For a great many years, Ohio has been a renowned salt-producing state. Its rank, during much of the last quarter of a century, has been either third or fourth. In 1908 only two other states, Michigan and New York, produced more salt. No one knows just how long salt has been manufactured in Ohio. White men have been boiling brine in the state for over a century. The few salt licks early discovered by the first settlers were of great value to them.

Early development. Much interesting history is connected with this natural resource. This history, the geological association of salt deposits and the methods of working it, have been thoroughly investigated by the State Geologist, and so clearly described that I here quote from a recent publication of the State Survey:

> Probably the first attempt to make salt on land now forming part of the state was in 1798. The locality was the old Scioto salt works on the banks of Salt Creek in what is now Jackson County. These salt springs were well known to the buffalo and other wild animals, long before the white man discovered them. Buffaloes came in herds, forming well beaten paths, recognizable as late at least as 1837. Regular pilgrimages to the licks were made by these animals until they were driven from the territory. That they were loth to abandon so favored a spot is shown by the fact that the last buffalo seen native in Ohio was near these licks, the date being 1802.
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> From earth works near the licks it has been thought that the Mound builders appreciated the locality as well as did the lower animals. Later the spot was a favorite with the Indians; the men killed the game which came for brine, while their squaws busied themselves making a little salt. Wells were not dug, the Indians simply taking the brackish water from the creek at low water stage and evaporating it. The last of their old salt pans was blasted out in 1899. Pilgrimages were made to the licks each summer by the Indians until about 1815.
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> The date of the white man's discovery of the licks is not known, but is was probably early in the eighteenth century by Canadian fur traders. The Virginia colonists knew of them at least as early as 1755. In 1795 a company of white salt boilers settled on the licks, and the camp is said to have grown quite large before the close of the century.
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> Officials of the federal government soon learned of the licks, and prompt action was taken to prevent their falling into the hands of parties who might make a monopoly of them. Thus in 1796 Congress passed an act providing for the sale of lands northwest of the Ohio River, but expressly reserved for future disposal the area containing these licks.

No arrangement was made, however, for operating the licks, but this was done a few years later when the territory became a state.

Early wells at these licks were quite shallow, varying from 20 to 30 feet in depth. The brine was correspondingly weak, from 600 to 800 gallons being necessary to make a bushel of salt. The product had a dark color and was otherwise inferior, but it was so much better than none that it commanded a high price.

Other pioneer wells were located on Salt Creek about nine miles southeast of Zanesville, on Duck Creek in Noble and Washington counties, and in the valley of the Muskingum. In all of these the salt industry started near the beginning of the nineteenth century, probably about the time of the state's admission into the Union. It is worthy of mention in this connection that several of these wells demonstrated the presence of petroleum and natural gas, though advantage was not taken of the discovery.

April 30, 1802, Congress passed the enabling act preparatory to Ohio becoming a state, the act providing, among other things, that an area of 36 square miles containing the Scioto salt springs shall be granted to the state for the use of its inhabitants. The legislature was empowered to frame regulations governing the use of the licks. The whole object seems to have been to prevent individuals or companies from obtaining a monopoly of them.

The first state legislature met March 1st, 1803, and soon considered leasing the salt licks. An act became a law April 13, 1803, which provided:

(1) That the state shall keep an agent for one year at the licks, who shall issue license to salt makers, collect the rent, study the geology of the region, and in other ways look after the state's interests.

(3) That no person or company shall use more than 120 kettles.

(3) That persons making salt shall pay to the agent three cents per gallon, payable quarterly, on the capacity of the plant.

April 14, 1803, the two houses met together and elected James Denny agent as provided for in the act referred to above.

In January, 1804, a second act relating to the licks was passed. This described more specifically the lots that might be rented for salt purposes, fixed the rent at four cents per gallon, and required the agent to inspect the salt. The rent was changed February 20, 1805, to two cents per gallon; February 13, 1808, to one cent per gallon; and January 19, 1810, to one-half cent per gallon.

The quantity of salt produced did not meet the expectations of the legislators, and an act was passed February 17th, 1812, to encourage deeper drilling. Similar acts were passed in 1813, 1814, and 1815, the last requiring a depth of 350 feet. It is reported that the honest driller went 100 feet deeper than the law required. A stronger brine was found, but the quantity was not ample.

According to Hildreth, the region was at its zenith of activity from 1806 to 1808, when twenty furnaces were in action, each averaging from fifty to seventy bushels of salt per week. When stronger brines were found on the Kanawha and other localities, the Scioto licks were at a disadvantage, the result being that the industry languished and was finally abandoned.

In 1818 the legislature announced that the salt licks were no longer a success, and asked Congress to permit the state to sell the land. This request was not granted until the closing days of 1824. In June, 1826, a three days' public sale was held and all lands not sold during that time were disposed of privately.

The act of Congress which provided that the Scioto salt licks should be reserved by the state also provided that where other licks were found, the enclosing land, 640 acres in area, should in a similar manner be retained by the state. Under this provision it appears that one tract was reserved on Salt Creek in Muskingum County, and another one in Delaware County. These three localities were the only ones in Ohio known at that time where salt licks existed. These tracts also seem to have been disposed of by the state in 1826.

It is said that as late as 1808 the wells penetrated the mantle rock only. The first effort to secure brine in bedrock is reported to have been made in the valley of the Great Kanawha, near Charleston. At first these wells reached depths ranging from 70 to 80 feet, but later extended to 350 feet. The brine was found to increase in strength with the depth, a discovery of great importance. In some places, however, deep wells were not a success, for example those of the Scioto salt licks.

In 1817 drilling began in the Muskingum valley, the first well having been located a few miles below Zanesvillle. Two years later a well was drilled in this town, water furnishing the power. These wells, however, seem never to have been profitable. Farther down the valley results were more favorable, wells existing at short intervals for a distance of 30 miles. Finding that the strength of brine increased with the depth, wells were drilled 850 feet deep, when a brine of such strength was found that a gallon made one pound of salt. By 1833 this valley is reported to have produced between 300,000 and 400,000 bushels per year.

Among other places producing considerable salt at about that time may be mentioned Yellow Creek, Columbiana County, the valley of Hocking River in Athens County, and Leading Creek in Meigs County.

Drilling in those days was a laborious process. A hole from four to six feet in diameter was dug through the surface material into the bed rock. Into this hole, called the "head," was placed a hollow sycamore log known as the "gum," or in its stead a rectangular tube constructed of planks, to exclude surface water. At the lower end of this drilling began. In early years the spring pole was used, men furnishing the power. This was succeeded by the treadle, a horse doing the work. In still later years steam was used. During the first part of the century work continued as a rule day and night, the men working in shifts or tours of six hours each. Progress was very slow. It is stated that six feet were considered a large day's work. Caving was usually prevented by the insertion of a copper tube, though it does not appear that long strings of this tubing were used.

The salt was made by evaporating the brine in large iron kettles, each holding from 60 to 80 gallons. These were set in a row over a flue which terminated at one end in a chimney. The fuel was wood taken from the adjacent forests.

The brine was pumped from the wells into a tank constructed of wood, and connected by tubes made of the same material with the kettles. After having been boiled for a time the brine was dipped into a cistern where it was allowed to cool and settle. In this manner such material as had been mixed with the water in a mechanical way was deposited, and also oxide of iron, which was at first dissolved in the brine, but was made insoluble by boiling.

When the settling had been completed, the brine was again conveyed by wooden tubes to certain ones of the row of kettles, known as "grainers." Into these was thrown a small quantity of clay which served as a nucleus for any remaining impurities, the whole being skimmed from the surface of the kettles. Beef's blood soon took the place of the clay, and this crude method is still followed in one small plant.

When salt had been precipitated in the kettles by boiling, it was thrown into "drainers" and the mother liquor, containing principally calcium chloride, drained off. The salt was then dumped into a shed known as the "salt house," and the drying completed. It was then barreled and marketed."[8]

Geological Relations. For several years salt has been produced in two sections of Ohio: one near the Ohio River, centering at Pomeroy; and the other in the northern part of the state in Medina, Summit and Cuyahoga counties. The wells near the Ohio river seldom are more than 1600 feet deep. These wells get their best brine from the Berea formation, but a brine of lower specific gravity is found at two or three shallower depths. The brine is pumped to the surface and evaporated. East of Pomeroy, deeper drilling is required to penetrate the Berea formation, because of the dip of the strata. While at many points in the state, wells in the Berea give a brackish water, in few localities is the water sufficiently brackish to make salt reduction profitable. Not infrequently a farmer drills a well for drinking purposes, in the sections where the Berea is on or near the surface, and the water is so salty that it cannot be used for his stock.

The salt wells in the northern part of the state all penetrate rocks of the Salina series which contain numerous beds of rock salt. The wells in Medina and Wayne counties are about 2700 feet deep, while in the vicinity of Cleveland they seldom need to go more than two thousand feet. The thickness of the individual beds varies from five to sixty feet. Water is pumped into the wells which forms a solute that is pumped out and evaporated. Some of the wells not far distant from each other have been operated so long that they now open into a single cavern which has been developed by the gradual solution of the salt, from the bottom of either well.

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[8] Dr. J. A. Bownocker, *Geological Survey of Ohio, Bulletin No. 8*, (1906), pp. 9-12.

Origin of salt. Above the Silurian, the formations bear their salt in the form of brines, that is, saline water exists in the rock. It is possible that this brine represents small particles of salt originally deposited with the sediments; ground water, circulating at a later date, may have dissolved these small bits of salt, thus producing the brine. Again it has been suggested that the salt water, with which the sediment was saturated as it was deposited, may have been retained; this would be possible, provided the saline sediment immediately overlies an impervious bed and is also capped by an impervious bed; thus the brine would be imprisoned. When we recall, however, that jointing exists in almost all rocks, it hardly seems probable that imprisoned waters would remain in these sediments through much geologic time.

Much speculation has arisen from the great thickness of rock salt frequently found in some localities. In this country a homogeneous bed 325 feet thick has been bored through, but at Sperenberg, Germany, a bed 3600 feet thick has been reported. Geologists suggest that rock salt probably represents evaporation and precipitation in basins containing sea water, isolated from the ocean. As the water in these basins, shut off from tidal influence, evaporates, their level is lowered, and by the seeping through the isolating barrier, water from the sea is constantly added. This supply of sea water and its continuous evaporation would in time form a bed of salt, the thickness of which would be conditioned upon the continuance of the above factors. It is known that today several depressed areas contain bodies of water to which drainage is constantly being added, but from which there is no flow; the only escape is by evaporation; such bodies of water are saline, for example, the Great Salt Lake, Caspian Sea, Kara Burgas, Aral Sea, and the Dead Sea.

GLASS SAND

In recent years Ohio has attained an important position as a glass sand producing state. The rank, however, that any state may assume in reference to this natural resource is conditioned generally upon the development of glass factories within its borders. About twenty-five years ago this state began to produce gas extensively. As a result many industries were started, and among these the manufacture of glass. If it had not been for the natural gas of Ohio, it is doubtful whether the state would now rank fourth as a producer of glass sand.

Sources. Long before the discovery of natural gas fields some glass sand was prepared for the market. This came from the Silurian rocks outcropping in Lucas County. Interstratified with the Monroe formation at Sylvania, are beds of sandstone, 15 to 20 feet thick, which contain very pure silica. In 1863 quarries were operated at this place, the sand being shipped to Pittsburg for the manufacture of "pure flint glass,"[9] and later at Holland in the same county. These quarries doubtless contain the purest silica for glass sand of any in the state. More sand is prepared for the market, however, in the central part of the state, where the Mississippian and the Pennsylvanian rocks come to the surface. The Black Hand formation of the former period furnishes a quality of sand that is prized for certain manufactures. At Toboso a remarkably thick deposit of this rock is operated by the E. H. Everett Company; the sand there produced is used chiefly by the American Bottle Company at Newark. Other quarries involving either this formation or sandstone horizons of the Pennsylvanian period are worked in Perry and Hocking counties, particularly by the Central Silica Company of Zanesville. Quarries in Tuscarawas, Holmes, Summit, Wayne, Coshocton and other counties in east-central Ohio furnish the glass sand for local consumption; many of these glass plants, however, were forced out of business by a shortage in the supply of gas.

Preparation for market. After mining, the rock is crushed and ground, usually to the extent of reducing the sandstone to its original components. This loose sand is then washed, dried, and screened. The principal reason for the fine grinding and washing is to get rid of certain impurities that make the sand less valuable; among these are clayey materials most of which may be washed away. In screening, the sand is often graded in accordance with different meshes; some of the plants market, as a by-product, the coarse material which makes fair ballast for roadways, or good gravel for concrete work. The sand from many of the quarries in the central part of the state contains iron, which makes it impossible to manufacture a light-colored glass. The product of these quarries is usually taken by factories that produce amber and green bottles. As a whole, the glass sand quarries of Ohio do not furnish raw material for the better grades of glass.

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[9] Gilbert, G. K., *Geological Survey of Ohio,* vol. i, (1873), p. 582.

OTHER SANDS

Molding sand. Foundries use this sand in making molds for castings. The essential qualities of such a sand are: (1) It must be sufficiently aluminous to hold its shape when patterned to form a mold, as sometimes the patterns are delicate. (2) It must be refractory, otherwise the molten iron would fuse and spoil the mold. This requires a high percentage of silica in the molding sand, as quartz does not melt at such temperatures as will keep iron in a molten condition. (3) The molding sand must be coarse enough to allow gas to escape, but at the same time it must hold the molten iron in shape; and it should not contain much clay.

Many surface deposits in Ohio furnish excellent molding sands. Only New York and Pennsylvania produced more than Ohio in 1908.

Building sands. In the production of this sand, Ohio ranked fourth in 1908. It not only provides all used within the state, but ships to adjacent territory. Here again is a natural product, the marketing of which depends a great deal upon building trades. Where population is sparse, this sand would not be in demand. In the parts of the country where population is dense, and there is activity in building, great quantities of sand are called for.

Engine sand. In recent years the demand for this sand has been increasing. Formerly it was used only on those parts of railways and street car lines involving grades. The sand is sprinkled on the rail, thus increasing the friction surface and enabling the car wheels to hold. Engines and street cars are generally equipped with sand bins, and the sand is sometimes used also on level stretches when the tracks are wet. According to *Mineral Resources* for 1908, Ohio ranked fourth in the production of engine sand.

Furnace sand. The demand for this is connected chiefly with the brick making industry; the sand is used between the bricks as they are placed in the kiln. This film of sand, which does not fuse under the temperature for burning brick, keeps the bricks from baking together. In still other industries, there is a demand for furnace sand. In the production of this sand, Ohio leads all the states.

LIME

According to the government reports for the year 1908, only Pennsylvania produced more lime than Ohio. Ohio contains a wide belt of limestone outcrops. These involve rocks ranging from quite pure calcium carbonates to a dolomitic amount of magnesium.

Formerly local kilns were operated at many points in the state. Now this industry is confined to certain centers, among which are Kelly's Island, Marblehead, Sandusky, Springfield, Cincinnati, and Marble Cliff near Columbus. This centralization is the result of modern business methods. Competition has led to the invention of machinery, which makes a great difference between the modern lime plant and plants of a generation ago. Not only the sources of raw material, but the shipping facilities for the finished product, are factors in the location of a lime plant.

The hydrated lime is to-day usually marketed as an impalpable white powder. This is the ordinary lump lime slaked, and powdered by grinding.

Uses. The various building trades require great quantities of lime, mostly as a mortar or wall finish. Several chemical industries also require lime. Much is used in the manufacture of glass, flint and plate glass particularly. Farmers have learned the value of lime on acid and clayey soils. Tanneries, paper mills, and sugar factories consume quite an amount of lime, as do also the manfacturers of basic steel, and of refractory brick. It enters also into the manufacture of soap and glycerine; its use as a disinfectant is increasing.

Sand-lime brick. In 1901 at Michigan City, Ind., an artificial sandstone or sand-lime brick was made. This new industry has shown a healthy growth. Some plants have been established in Ohio. Others doubtless will come into operation because of the abundant lime manufactured here.

This artificial sandstone is simply a combination of sand and lime. A comparatively pure sand is required; if the sand contains much clay, the product weathers more rapidly, especially in our climate. Usually coarse and fine sand are combined, three parts of the former to two of the latter; with one part of lime, twenty parts of sand are used. The lime is slaked, then the water and sand added, and thoroughly mixed. Later it is shaped into bricks, and hardened, generally by steam pressure.

With the widespread glacial deposits of Ohio and the high percentage of sands which they contain, it is natural that this industry should grow.

CEMENTS

Under this heading are included several mixtures each of which, with water, will make a mortar that hardens as a binder, that is, has cementing powers. The cement hardens or sets because the finely ground rock takes up the water and crystallizes or sets. The cement industry may be associated with the production of lime, though not necessarily. In this state three kinds of cement are manufactured.

In the production of cements, Ohio does not rank high. The position of any state in this product is conditioned by many factors. The cements are used as building materials, consequently the demand is greater near the larger cities, as activity in building is a matter of population. The mere fact that a state may contain abundant raw material for the manufacture of cements does not insure that plants will be erected. Competition is usually rife in supplies for building trades. Oftentimes the prosperity of a cement plant depends entirely on freight rates, which have to be figured in competition.

Natural cement. This is also called Roman cement, and Rosendale cement. It is made from a limestone which contains 30 to 50 per cent of clayey and sandy impurities. When this silico-aluminous limestone is burned, it will not slake unless finely ground. The ordinary carbonate, when burned, will slake in the lumpy condition. Of the various cements made in this country this is the oldest. It was used for structural purposes early in the last century. Few plants are operating now in Ohio. The best, so far as I am able to ascertain, is that at Defiance.

Pozzuolane cement. This is a very old kind of cement. It was used by the Romans, as the name indicates. At first it was manufactured by combining slaked lime and volcanic tufa. The volcanic matter carried a high amount of silicic acid, which combined readily with the hydrated lime. In this country furnace slag which was cooled quickly is substituted for the tufa. This slag is a by-product of blast furnaces, and is usually discarded. A few furnaces, however, are now producing pozzuolane cement.

Portland cement. This is an artificial mixture of clay and calcareous matter. Any raw material which furnishes silica, alumina, calcium oxide, and some iron oxide, may be used. After these ingredients have been thoroughly mixed, they are burned to a clinker, and then ground fine.

Quite a variety of raw materials contain the required ingredients: clay and marl; clay, or shale, and limestone; pure limestone and argillaceous limestone.

The largest Portland cement plant in Ohio is at Castalia. Here they use travertine, a calcareous deposit of the springs that issue from the limestone in that vicinity, and soft clay. A plant at Middle Branch, in Stark County, uses a limestone and an associated shale. One in Logan County uses marl and glacial clay. At Wellston, Jackson County, is a plant built at some distance from the source of its raw material; the question of shipping facilities for the finished product decided this location.

ABRASIVES

Natural. For many years this state has led all others in the production of grindstones and pulpstones. The Berea formation furnishes most of this material. For use as a grindstone the rock must be homogeneous in texture, and its components must be sufficiently cemented to endure, but not so completely cemented that the stone will wear smooth.

Pulpstones are sometimes very large, weighing from two to four thousand pounds and even more, and measuring four to five feet or more in diameter. These stones must stand much heat, since in grinding wood for pulp in the manufacture of paper, they are continually exposed to hot water. Formerly this country imported practically all of its pulpstones from England; now the Berea rock is found to answer the purpose.

Ohio also supplies scythestones and whetstones. These require a finer grained sand rock than will answer for either grindstones or pulpstones.

Artificial abrasives. In recent years natural abrasives have had to compete with artificial stones. Several of these are now being made in this country after German formulae; this competition is not important. A plant at Niagara Falls, however, is turning out a product with which our natural stones do not so successfully compete. Carborundum, the artificial abrasive there manufactured, was made possible by the supply of electrical current generated at the falls power plant. This abrasive is made by fusing together sawdust, granulated coke, the source of which is the carbonaceous residue in the distillation of petroleum, and a very pure glass sand. Only by the electrical furnace is it possible to secure commercially the required degree of heat. The fused product is ground to various degrees of fineness, and corresponding abrasive instruments are made, ranging from a fine razor hone to a very coarse tool. Since carborundum is harder than anything in nature, save the diamond, one appreciates how natural abrasives find this artificial product a strong competitor.

NATURAL GAS

Natural gas and petroleum are associated in nature, and man has frequently secured both from the same well. The reason for this association will appear in the discussion of their origin.

Early history. "Knowledge of the existence of oil and gas in the rocks of Ohio dates back almost to the period of the state's admission into the Union. This resulted quite largely from the search of the pioneers for that necessary article, common salt. Thus a well drilled in 1814, near the village of South Olive, Noble County, with this in view found such a pressure of gas that it threw the water and some oil to a height of from 30–40 feet, and these eruptions were continued as late at least as 1838. About the same time both oil and gas were discovered in Washington County to the south. The petroleum was called Seneka oil, and was used in a small way for medicinal, illuminating, and lubricating purposes. Similar results were secured at many points in the southeastern part of the state, but the oil and gas were regarded as a nuisance. The former ruined the brine for the manufacture of salt, and the gas was regarded too dangerous. Deep wells, however, did not furnish the only evidence of this wealth stored in the rocks below. Sometimes ordinary water wells would liberate small quantities of oil or gas, and occasionally these products were found in still shallower excavations. At a few points oil was found as a very thin film on the surface of streams, and occasionally gas escaped with spring waters, the combination having been known as gaseous springs. It is interesting to note that evidence of this kind led later to tests at several points, with the result that valuable pools of oil and reservoirs of gas were discovered in Washington, Morgan and Knox counties, and finally the great Trenton limestone field itself."[10]

Pre-commercial use. Near Findlay, in 1836, a well was dug for water; at a depth of ten feet it had to be abandoned because of gas. Two years later a well was dug in the village; it also showed a strong odor of gas, and could not be used for water. The owner ingeniously inverted a sugar kettle over the top and conveyed the gas to his house through a wooden pipe, connecting it up in the fireplace by using the barrel of an old gun. In 1884 gas was still in use in this fireplace.[11]

At East Liverpool, in 1859, a well was drilled to the depth of 450 feet. It is probable that this hole was made for salt. Gas, however, showed, and no salt was found. In 1865 other wells were drilled, this time for oil, most of them producing some gas. In many instances the gas was regarded as a nuisance and the wells were abandoned. In one case, the gas was piped and used in a house or two and later in a pottery.

At Painesville, in Lake County, a 700-foot well was drilled in 1861. This was put down purposefully for gas which the owner secured in sufficient quantity to use in his home. The supply was still good in 1885.

Since 1865 wells have been drilled into the Ohio shale in Lorain and other counties along the lake, where this shale is near the surface. The supply of gas from these wells was in no case great, but usually ample for domestic purposes. Shallow wells are still being drilled in this area and most of them are successful. The fact that many houses have been continuously using gas from these shallow wells for cooking purposes and in some cases also for heating is very suggestive of the advantage in conserving gas, as will appear in the following pages; there has been much recklessness and wastefulness in the use of gas in Ohio, as in other states.

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[10] Dr. J. A. Bownocker, *Geological Survey of Ohio, Bulletin 1,* (1903), p. 31.

[11] *Geological Survey of Ohio*, vol. vi, (1888), p. 109.

Commercial exploitation. Inspired by the discovery of rich gas areas in adjacent states, people in Ohio, about 1884, commenced to drill deep wells. In locating these wells, there was very little judgment used, save where indications of gas already gave promise. Not infrequently the advice of men who knew the geologic structure and the probabilities of certain areas producing gas, was ignored. A spirit of reckless gambling pervaded most communities for several years.

At Findlay, however, there was already good reason for suspecting the presence of gas. Drilling began there in 1884, and by the end of the next year thirteen wells had been completed; some of these were big producers. Industries were attracted to the town by grants of free fuel for five years, and in some cases by grants of building sites in addition. Factories went up on all sides of the town which in less than five years increased in population from 5000 to 25,000. Reckless speculation followed, and gas was wastefully used, in spite of the admonitions of more judicial citizens. Many urged that nature was making the gas as fast as it left the wells, but by 1888 the flow from some of the wells was already diminishing.

The wells at and near Findlay led to drilling in adjacent territory. On all sides the drill was at work, and before many years men had learned the outlines of the paying territory. Several towns in the northwestern part of the state went into the gas business. In every case special legislation had to be secured at Columbus, allowing the municipalities to bond themselves to put down wells. Business competition led to these methods. The boom at Findlay encouraged Fostoria, Tiffin and other places to attempt the same thing. Manufactories were installed, and other wildcat projects sometimes encouraged.

It was found that the paying territory for gas wells extended northward from Findlay, through Bowling Green and North Baltimore. But in this whole area, by the year 1890, the gas flow had so declined that numerous factories either shut down, or removed from the towns. If some federal or state power could have imposed upon these communities an appreciation of this natural resource, they might have made more permanent progress in consequence of its discovery. As it was, however, business disaster overtook scores of individuals, and numerous companies, as well as several municipalities.

South of Findlay, in the vicinity of St. Mary's, another gas field was located, and its early days had a similar history. In more distant parts of the state, the rapid growth of Findlay inspired communities to exploit their area. At Lancaster, gas was discovered in 1887, and this field, by further drilling, was extended both north and south; on the north it reached through Licking into Knox County, and southward into Hocking County.

Practically every county in Ohio, before the year 1890, was tested for gas. But in no location, so far as I can learn, was there any thought of conserving this resource. Even the doleful experience of the towns in the northwestern part of the state did not seem to drive the lesson home. So long as any gas flowed, much of it was wasted.

During the twenty-five years since the Findlay discovery several important gas areas have been found. Even yet, now and then, a new reservoir is located. But a more systematic study of nature's way of hoarding gas has tended to less hazardous testing.

Conservation. It probably is not far from the truth to say that as much gas has been wasted as has been used in Ohio. It is natural for capital to seek an immediate return. Men are tempted to get the largest possible yield from their investments in the quickest time. Human selfishness is not always wise, in spite of the fact that the progress of a race owes much to the law of survival. This waste of gas in Ohio, as well as in other states, has been allowed to continue already more than a generation. Field after field has given out. Factories have remained in one field until the gas was exhausted, and then some other community, discovering gas, has invited them there. Wildcat methods have been very common in connection with the use of this natural resource. In every gas community citizens will recall the details of waste. Only in the last two years is there noted a tendency to reserve gas for domestic purposes, but the movement has not assumed gratifying proportions; the largest consumers are supplied at a low price; manufacturing establishments are consuming in a few years gas that would be ample for a century of domestic use. Other fuels can be used conveniently in manufactories, whereas no fuel in houses can take the place of gas.

OIL

Early history. Along the Little Muskingum River, in Washington County, oil was found early last century, in connection with drilling for salt water. This matter was referred to in a letter written by Dr. S. P. Hildreth in 1818:[12]

> They have sunk two wells which are now more than 400 feet in depth. One of them affords a very strong and pure water, but not in great quantity. The other discharges such vast quantities of petroleum, or as it is vulgarly called, "Seneka oil," and besides is subject to such tremendous explosions of gas for several days that they made but little or no salt. Nevertheless, the petroleum affords considerable profit, and is beginning to be in demand for lamps, in workshops and manufactories. It affords a clean, brisk light when burnt this way, and will be a valuable article for lighting the street lamps in the future cities of Ohio.

In other parts of Ohio, early salt wells were not infrequently abandoned because they gave either gas or oil. It was seldom that either of these fuels were considered valuable.

The first dealers in crude oil in Ohio appear to have been "Bosworth, Wells, and Company" of Marietta. "The firm shipped oil to Pittsburgh, Philadelphia, Baltimore, New York, St. Louis, Peoria, Chicago, and Cincinnati. From 1848 to 1857 the firm received 33 cents per gallon for the oil, and from 1857 to 1860 40 cents per gallon."[13] At that time there were no refineries nearer than St. Louis. The oil was used for various purposes, but had always had some market as a medicine.

The famous Drake Well put down at Titusville, Pennsylvania, 1859, inspired testing in adjacent states. Within a year, many holes were sunk in West Virginia and Ohio. As in the case of gas, early prospectors were attracted by surface indications of oil, and usually did their first drilling in these localities. I will refer particularly to a few of these early efforts to secure oil.

Washington County. Near Macksburg, in 1860, a well was drilled 59 feet into the sandstone, and a very heavy oil was found. This oil was too heavy to burn in lamps, but had a ready market as a lubricant, commanding a price of $28.00 per barrel. Other wells in the immediate region were drilled at once. Great excitement prevailed. Companies were organized and property changed hands frequently, at increasing prices. For a 200-acre farm, near the original well, $300,000 was paid. None of these early wells were great producers; not many of them flowed, but their shallow depth made pumping by hand relatively easy; the wells were drilled by hand.

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[12] *Geological Survey of Ohio, Bulletin 1*, (1903), p. 148.

[13] *Ibid.*, p. 149.

At Cow Run, in 1861, the first well was sunk; at a depth of 137 feet oil was discovered. This oil was pumped by hand, two men being able to take out about 50 barrels a day. Here again great interest was aroused, and fabulous sums were paid for territory. The methods of these ventures almost seem beyond belief when read to-day. Even had a "gusher" been discovered, one could hardly understand the lack of business conservatism.

Noble County. Not far north of Macksburg, in 1860, a few wells were drilled along Duck Creek. Some oil was reported in most of them, and a moderate business was carried on. I find no record of such recklessness as prevailed in Washington County.

Trumbull County. Early in 1860, a few wells, ranging from 40 to 60 feet in depth, were sunk into the Berea sandstone near West Mecca. These are reported to have yielded ten to fifty barrels each at first; later, the daily yield dropped, and most of the wells were short-lived. It is interesting to note that, on account of the cheapness of labor, a farmer would get back his investment for sinking the well in case it produced two barrels. So far as I can learn, this is the only county in the state where men have tried to obtain the oil by mining; a shaft 52 feet deep was sunk, and from its bottom a tunnel was excavated 32 feet to the east, and 30 feet to the west.[14] These experimenters reasoned that if oil would gather into a six inch drill hole, more would collect in a tunnel. The venture was a disappointment. The Trumbull County oil area has only an historic interest.

Morgan County. The first well, 65 feet deep, was drilled in this county in 1860. It yielded eight barrels per day and continued to produce for twenty successive years. The well occasioned intense excitement; speculation at once became rife. A stock company with a capital of one million dollars was organized. One-half of the initial stock was sold in New York City; the remaining half shortly advanced 50 per cent in price. The 400-acre farm containing the original well was purchased for $375,000. Immediately another well was put down, which yielded twenty barrels per day. The spirit of speculation became more intense. Record shows that a one-half acre lot containing a ten-barrel well, sold for $10,000.

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[14] *Geological Survey of Ohio, Bulletin 1,* (1903), p. 301.

Wood County. As an oil field, this is the banner county of Ohio. The first oil, however, was discovered in drilling for gas, and occasioned very little interest. Drilling purposefully for oil commenced in 1886. Between the years 1891 and 1899, 7661 wells were drilled; 88 per cent of these produced oil. While in this county, no phenomenal gushers were found, it was uncommon to get a dry hole; the county is still producing much oil.

In other counties. The drilling for gas elsewhere in northwestern Ohio shortly disclosed the presence of oil. Among the very first wells at Findlay, oil was found. Usually, however, it was regarded as a nuisance. Some of the companies, upon failing to obtain gas in satisfying quantities, gave attention to the oil; as a result, these wells were pumped, and others put down purposefully for oil. That section of the state, since the gas so shortly gave out, was, in a measure, financially redeemed by the great abundance of oil. Many of the wells before long fell into the hands of companies that were more wisely managed, and northwestern Ohio received great profit from the oil.

The handicap of early wells. Following the year 1860, and the immediate boom in some sections of southeastern Ohio, the war had much to do in checking activity. Nevertheless, in the nature of things, these early wells were seriously handicapped. The oil produced, in many cases, had to be hauled several miles either to a railroad, or to a river, where it was transferred to boat. The method of piping oil had not yet been introduced. Piping methods, however, were introduced in time to make some of the territory more profitable. The Cow Run wells were piped to the Ohio River in 1868.[15] The tributaries had sufficient depth of water part of the year for floating boats, but the means of storing the oil were inadequate to work the wells the entire year. Nevertheless, all of the territory of southeastern Ohio became inactive, and for over a decade following the war little business was done.

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[15] *Geological Survey of Ohio, Bulletin 1*, (1903), p. 154.

STRATIGRAPHY OF OIL AND GAS

Below I give a list of the periods and the formations in which the oil and gas of this state occur.

Ordovician. The oldest rocks in the state, producing oil or gas, are found in this period. The Trenton limestone is reached in the western part of the state at a depth of about 1100 to 1500 feet. This formation is found on the surface next to the Ohio River, but it dips towards the north, on account of the arching of the Cincinnati anticline. The Trenton oil and gas fields appear to be associated with this deformation. Elsewhere in the state wells have been sunk into the Trenton but without success. The farther east one goes, the deeper it is necessary to drill. The extreme depth of a well in this limestone is reported as 3440 feet; this well is near Ironton.[16]

Silurian. Two formations of this period have economic value. The Clinton sandstone supplies much gas in Knox, Hocking, Licking and Fairfield counties. Some oil also occurs locally in this sandstone. In Jefferson and Ashtabula counties gas is found in the sand horizons of the lower Helderberg; very little oil, however, occurs here.

Devonian. In one formation of this period, the Ohio shale, gas has been found for a great many years. This formation outcrops along the southern shore of Lake Erie, westward nearly to Sandusky. Probably no formation of the state contains so many wells. These are all shallow, seldom going over 800 feet. No one well has ever produced commercial gas, but has produced sufficient to supply one or a few houses. The wells are long-lived; it seems not unlikely that no formation contains more gas than does the Ohio shale.[17] The gas appears to be widely distributed in the formation, instead of being confined to a few reservoirs, as is the case in most gas-producing rocks.

Mississippian. Two formations of this period have commercial value in oil and gas. The Berea sandstone, which outcrops along an east-west line south of the lake, and then turns southward across the state from the eastern side of Huron County, dips to the east quite rapidly. In Washington and Monroe counties wells had to be drilled about 2000 feet, to reach the Berea.[18] The Berea has been drilled in widely distant parts of the state, and whenever penetrated it shows at least a trace of oil and gas, but has produced in commercial quantities only in the following counties: Lorain, Medina, Trumbull, Columbiana, Stark, Jefferson, Harrison, Belmont, Guernsey, Monroe, Noble, Vinton, Perry, Athens, Morgan and Washington.

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[16] *Geological Survey of Ohio,* vol. vi, (1888), p. 304.

[17] *Ibid.,* p. 413.

The Logan group of the Mississippian, in Monroe and Washington counties, produces oil. These were oil centers of considerable importance in earlier days. The three horizons of the Logan that gave oil have been named by drillers in descending order: Keener sand, Big Injun sand, and Squaw sand. At only a few points outside of these two counties, does the Logan yield oil or gas in commercial value.

Pennsylvanian. Several sandstone horizons in the "Coal Measures" contain some oil and gas; each has a designation, usually a name associated with the locality where it was first found to be oil-bearing. The wide distribution of Pennsylvanian rocks throughout the state has led to much testing, but the successful wells are confined mostly to Noble, Morgan and Washington counties.

Occurrence in rock. An interesting fact in connection with these natural resources is their occurrence in such a variety of rocks. Both oil and gas have been found in limestone, in shale, and in sandstone, even sandstone that is conglomerate in structure. It is usually held that only in the porous zones of these rocks do we find oil and gas. Generally, only dolomitic limestone is gas-bearing; this phase of limestone is much coarser in texture, due to its crystalline structure, than is the purer calcium carbonate. The shale horizons are usually fissile and much broken by joints; while sandstone is always more or less porous. So far as the eye can detect, most of these rocks do not appear to be very porous, but, when examined under the glass, one is surprised at what a fraction of a given area the openings make. Sometimes a surface one foot square will show four square inches of combined interstitial spaces.

It has been found that oil and gas are not homogeneously distributed in any of these formations, but are usually localized in pools or reservoirs. Much has been written on the "anticlinal theory" of oil and gas. This explanation arose doubtless from the frequency with which paying wells occur in the upper parts of anticlines or near the axes of benches and terraces. In the Trenton limestone field, the wells seem to follow the axis or keep near the axis of the Cincinnati arch. Even beyond the zone of the pronounced anticlinal fold, where the formation contains only a bend or bench, paying wells are generally confined to the terrace. Elsewhere in the state, profitable drilling has disclosed a similar arching of the formations. This coincidence of paying wells and disturbed areas in the rocks has suggested the "anticlinal theory" of the occurrence of oil and gas. This theory states that since oil and gas are lighter than water, they seek the higher parts of formations which are not horizontal, the oil overlying the water and the gas capping the oil. The influence of gravity would account for such a distribution of these substances.

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[18] *Geological Survey of Ohio, Bulletin 1*, (1903), p. 185, and p. 201.

ORIGIN OF OIL AND GAS

These valuable resources are not found everywhere. While they occur in geological horizons that differ much in age, they do not occur in all parts of any one formation. It has been demonstrated that the oil producing area of the Trenton limestone in this state is localized. The only formation which appears to have even a general distribution of oil and gas is the Berea, but the Berea does not in all places bear these fuels in commercial quantities.

The fact that both oil and gas are usually found together, gas always with oil, implies something common in their origin. Gas sometimes occurs without oil, but in gas territories oil is occasionally found. Petroleum gives off a gas that closely resembles natural gas. Furthermore,in areas producing both, if anything unusual is found in the composition of the one, the same peculiarity generally characterizes the other also. As an illustration, the Trenton limestone produces both oil and gas in each of which there is some sulphur; but if, in a particular section, the sulphur is lacking in one, it is absent also in the other. These, and several other reasons, lead us to believe that oil and gas have a common origin.

These fuels belong to the hydrocarbon group of natural products. The principal elements in them are hydrogen and carbon. With these hydrocarbons usually occur several of their derivatives. As a result, the hydrocarbons are very complex in composition. For over a century, students have been wrestling with the question of their origin, the interest usually centering about oil and gas. Two theories have been advanced; one has many advocates.

The inorganic theory. This is sometimes referred to as the chemists' theory for the origin of oil and gas. Stated briefly it is this: Steam, in the presence of carbides of iron or other metals, will form hydrocarbons. This is a laboratory demonstration. It is urged, therefore, that percolating ground water, reaching the deeper parts of the earth, produces steam which in the presence of carbides of metals forms hydrocarbons. If this theory operates in nature, both oil and gas, as well as other hydrocarbons, should be very widely distributed. The movement of ground water takes place through all rocks, those of both the continental platforms and the ocean basins. Man, much to his disappointment, has found that these fuels are localized; not many areas of any one continent have either oil or gas. The theory itself is perfectly tenable. This supposed natural plan for the origin of hydrocarbons is very similar to the artificial method of manufacturing acetylene gas. Only in the last few years has a line of investigation tended to show that hydrocarbons produced by steam and carbides of metals do differ from the hydrocarbons found in nature.[19] This difference I refer to in the next section.

The organic theory. In nearly every state, rock formations, bearing gas or petroleum, contain fossils of animals or of plants or of both. Some students urge that the hydrocarbons are formed by the slow distillation of this organic material. In the laboratory, men have made several of the hydrocarbon derivatives by distilling fish oil. Natural gas, too, frequently occurs in coal mines, known as "fire damp." Practically no oil or gas has been found in the crystalline rocks. Fossils do not occur in these rocks. Furthermore, rocks containing fossils sometimes have a very distinct petroleum odor; limestones on Kelly's Island is an example.

The organic theory, then, contemplates the slow distillation of organic remains in the rocks. Along certain tracts of the ocean borders, lakes and rivers to-day, organic remains, plant and animal, become buried by sediment, and very slowly putrefy or ferment. That in this alteration gas is evolved, you have only to recall observing bubbles of gas rising to the surface of streams and of other water bodies. In 1878 Radziszewski[20] suggested that the action of bacteria on buried organic matter plays an important rôle on the development of these hydrocarbons. It is known that the decay of plant and animal tissue is due entirely to the work of these micro-organisms.

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[19] *Economic Geology*, vol. iv, (1909), pp. 626-27.

Petroleum possesses a certain optical activity which is wanting in artificially produced hydrocarbons. This activity appears to be due to certain components not found in the artificial products.

> The first main general theory, that of the inorganic origin of petroleum, has been found to be inadmissable on chemical as well as on geological grounds, since petroleums so derived are optically inactive, differing from natural oils, while the facts of the occurrence of petroleum are opposed to the theory, and allow its application only to a few occurrences of hydrocarbons in igneous rocks where these cannot have derived their bituminum from surrounding sedimentary deposits.[21]

AMOUNT OF OIL AND GAS PRODUCED

Natural gas. Between the years 1885 and 1890 Ohio ranked second in the production of natural gas, only Pennsylvania supplied more. From 1891 to 1898 the second place was taken by Indiana, Ohio ranking third. Between the years 1899 and 1903 Ohio's position was fourth, West Virginia also producing more. But from 1904 to 1908 Ohio assumed again the third rank, Indiana falling into the fourth place.

Petroleum. As an oil-producing state, Ohio has been steadily decreasing since 1900, but its output of oil up to this time was remarkable, and should be given a prominent position in any discussion of its natural resources. The appended table from the *Mineral Resources* of the U. S. Geological Survey for 1908[22] shows the production for Ohio, as well as the entire output of the country; before 1876, the oil of Ohio was included in the figure for the whole country:

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[20] *Archiv. Pharm.*, 3, xiii, 455-59.

[21] Leonard V. Dalton: *Economic Geology*, iv, (1909), 630.

[22] *Ibid.*, p. 350.

(Barrels of 42 gallons)

Year	Ohio	United States	Year	Ohio	United States
1859		2,000	1884	90,081	24,218,438
1860		500,000	1885	661,580	21,858,785
1861		2,113,609	1886	1,782,970	28,064,841
1862		3,056,690	1887	5,022,632	28,283,483
1863		2,611,309	1888	10,010,868	27,612,025
1864		2,116,109	1889	12,471,466	35,163,512
1865		2,497,700	1890	16,124,656	45,823,572
1866		3,597,700	1891	17,740,301	54,292,655
1867		3,347,300	1892	16,362,921	50,509,657
1868		3,646,117	1893	16,249,769	48,431,066
1869		4,215,000	1894	16,792,154	49,344,516
1870		5,260,745	1895	19,545,233	52,892,276
1871		5,205,234	1896	23,941,169	60,960,361
1872		6,293,194	1897	21,560,515	60,475,516
1873		9,893,786	1898	18,738,708	55,364,233
1874		10,926,945	1899	21,142,108	57,070,850
1875		12,162,514	1900	22,362,730	63,362,704
1876	31,763	9,132,669	1901	21,648,083	69,389,194
1877	29,888	13,350,363	1902	21,014,231	88,766,916
1878	38,179	15,396,868	1903	20,480,286	100,461,337
1879	29,112	19,914,146	1904	18,876,631	117,080,960
1880	38,940	26,286,123	1905	16,346,660	134,717,580
1881	33,867	27,631,238	1906	14,787,763	126,493,936
1882	39,761	30,510,830	1907	12,207,448	166,095,335
1883	47,632	23,449,633	1908	10,858,797	179,572,479

CLAY

For a great many years Ohio has led the states in its clay products. The fact that a given commonwealth may market more clay products than any other does not imply a corresponding rank in raw clay. In Ohio, however, the supply of clay is very ample.

The term clay refers to deposits, which are combinations of pure kaolin with one or more of several other minerals, as silicates, oxides, hydrates, and sometimes also certain colloids or organic compounds. When rocks weather, the products are either clay or sand, or both. Silica and clay are the most common of all rock components. The purer the clay is, theoretically, the higher is its percentage of kaolin. Pure kaolin originates from the decay of feldspar which produces, upon weathering, a hydrous aluminum silicate. Between pure clay and the weathered products which are classified as clays, there is a wide gap. This fact accounts for several varieties of clay, depending upon the percentage of given constituents.

Clay produced by the decay of crystalline or other rocks *in situ* is termed "residual." Clays which have been deposited in water, or by running water, are "sedimentary." The sedimentary clays are either unconsolidated, or are in the form of more solid rock; surface clays belong to the former, while shale represents the second class. The clays of Ohio are all sedimentary in origin; we have extensive outcrops of shale or clay. Over much of the state the glacial drift is also a source of clay; locally "bowlder" clay is well developed. Another form of glacial clay occurs in the northern counties; this was deposited in the ice-front lakes, and is called "lake" clay. Wherever rivers are making deposits, clays accumulate; the flood plains of valleys are accordingly a source of clay.

Properties of clay. The character of a clay depends upon its constituents. These are numerous, involving commonly, lime, magnesia, silica, oxides of iron, alkalies, titanic acid, alumina, organic matter, and combined water. As the per cent of a particular constituent varies, the character of the clay changes accordingly. If much iron is present, the burned clay has a stain; red brick represent a clay carrying an appreciable amount of iron oxide. If lime is in excess, it acts as a flux in burning and often gives the product a cream color. Silica makes the clay more refractory, and lowers its plasticity, while organic matter or colloids increase its plasticity. The tensil strength of clay varies from a few pounds to four hundred pounds or more per square inch. The fluxes, such as magnesia, alkalies and lime, cause the clay to fuse at lower temperatures. Thus, it is seen that products made by burning clay must vary greatly in accordance with the constituents.

In the early days of clay working, men could learn only through experimentation. The chemistry of clays was little understood. At the present time, the haphazard method of using clays will not enable the manufacturer to cope with competition. He should know the chemistry of his clays and treat them accordingly, if he is to hold a place in business.

When properly burned, many clays are very enduring. Chemical changes are introduced by burning, the manner of the burning largely determining the change. The purpose of firing clay is to make it impervious and thus prepare it to better resist weathering. After the clay has been prepared, by grinding and mixing with water, so as to admit of molding or pressing into the form desired, this water is removed by slow drying. Next, burning removes the water of hydration, and further burning increases the hardness and density of the clay. But, to make the product enduring, the manufacturer must know at what point to stop the firing; if fired too long, the product crumbles easily. Mankind early learned the art of clay working. Burned clay products form the best evidence of prehistoric civilizations, and their success in thus treating clays is seen in the freshness of pottery that doubtless has been buried many thousand years.

Kinds of clay in Ohio. Complexity of the clayey compounds classified under the head of "clays," renders it impossible to, draw fast lines between different types. In practice, a clay is named in accordance with the use made of it. The same clay, however, is sometimes used for different purposes; hence clays are not yet definitely classified on the basis of their constituents. Indeed, two clays which are quite similar in the percentage of different clay-making constituents may behave very much unlike when burned; students cannot explain just why this is. Use is the final criterion in handling a clay.

The term "fire clay" applies to those horizons that provide a clay which does not melt under a very high temperature, as perhaps 1600° C. This term is generally used for the shale horizons that often underly coal beds. This form of clay is used in making fire brick, crucibles, furnace linings, and other refractory wares. The "coal measures" supply the large percentage of our fire clays.

Another form of this resource is called "pottery" clay because it is used extensively by potteries. Pottery clays include a wide range of materials, which are varied according to the product desired. Summit County, perhaps, has the best reputation for its potter's clay.

Ohio produces large amounts of brick and tile. For this work, a great variety of clays may be used; as a result, bricks vary much in color and in other characteristics. Very many kinds of clay are used in this state for making brick and tile. The competition does not admit of freight expenses in hauling the raw material. Brick and tile plants use a clay found near the plant.

Rank of state. In 1908, Ohio supplied one-fifth of the entire output of this country's clay products; while slightly over 42 per cent of the pottery manufactured in the United States came from Ohio. This rank is due, primarily, to the fact that the state has in it the requisite raw material, otherwise the manufacturing of clay products would not have started in the state. Since these manufactories have been established, and since the state does not contain some varieties of clay required, considerable raw material is imported, part of it coming from Europe. It should be remembered, however, that the clay industry was developed, primarily, because the state has the required raw material, and its home markets needed the clay products.

As time went on, specialized products were turned out for which raw material, not provided by the state, was imported; but the business owes its thorough establishment in Ohio to the great variety and abundance of clays present.

COAL

We have many references, made by early explorers and settlers, to coal being found within the limits of Ohio. In those days, the coal was not particularly appreciated because in most areas agriculture necessitated the removal of the forests, and people accordingly burned wood, not only in the houses, but in their manufactories, for a long time. In 1810 coal was mined near Talmadge in Summit County, and by 1818 it was shipped by river boats from Akron to Cleveland. When the Ohio Canal commenced to operate, mines were opened near Massillon, making shipments to Cleveland.

The Hocking Valley coal field was used locally for domestic purposes, but the demand did not increase till about 1831, when the salt boiling industry required brisker mining; by the following year, the branch of the Ohio Canal to Nelsonville, made it possible to ship coal readily, and more extensive mining began.

By 1833, coal was being mined systematically along the Ohio even below Wheeling. Two years later a steam towboat, owned by the Pomeroy Coal Company, began delivering coal to Cincinnati. Very shortly numerous boats appeared on the river delivering coal even as far as New Orleans. At Mineral Ridge, not far from Brier Hill, coal mining commenced in 1835.

Pennsylvanian rocks of Ohio. Formerly the term Carboniferous was applied to both these rocks and the formations now included in the Mississippian period. As students learned more about this entire series, it became evident that the conditions under which the lower members were deposited differed much from later conditions. For this reason, the early part of the Carboniferous was set off into a separate period, the Mississippian, and the upper part was named the Pennsylvanian.

About ten thousand square miles of the state's surface is covered by the Pennsylvanian formations. The entire thickness of this series approximates 1600 feet. In the lower part, conglomerates and sandstones are more common. Above these, the sandstone becomes more shaly, occasionally consisting entirely of shale. Throughout the whole series, limestone beds are irregularly distributed; they are seldom very thick, usually less than a foot. Elsewhere calcareous shales and sandstone appear. Scattered through the Pennsylvanian rocks, are found twelve to fifteen seams of coal. Four or five of these are of slight importance, being very thin, and containing so much clastic material that they have no value as fuels.

While the Pennsylvanian formations appear over so wide a surface of the state and have a considerable vertical thickness, it does not follow that the given beds themselves have a corresponding horizontal area. These sediments were laid down in shallow basins, bordering the sea, and some distance inland. The arms of the sea gradually contracted, thus giving the sediments a shingled attitude. Sixteen hundred feet, which is the estimated thickness of the several beds outcropping one above the other, does not mean that difference in the altitude of the youngest and oldest rocks of the series.

Methods of mining. In the early days, the outcrops of coal along the hill slopes attracted attention. These exposures were worked by drift mining, and since, in Ohio, the coal beds have been deformed but little, these shafts did not vary much from the horizontal. The usual dip of coal beds is from twenty-five feet to thirty feet per mile. Later, vertical shafts were used. So far as recorded, the first shaft of this kind was erected at Steubenville in 1856.[23]

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[23] *Geological Survey of Ohio*, vol. v, (1884), p. 323.

Men have long realized the extravagant methods of operating coal mines in Ohio, as well as in other states. Many years ago Professor Edward Orton, Sr., spoke[24] eloquently on this subject, realizing, however, that nothing could be accomplished without coöperation between the states; he showed how the loss from incomplete or reckless mining ranges sometimes as high as 25 per cent. In most cases, this is an irredeemable loss. As this fuel becomes scarcer, the methods of the earlier generation of coal operators and the conditions that accounted for their negligence and recklessness, may be cataloged among the activities of semi-barbarous men.

Centers of coal mining. There are many rock horizons in Ohio that produce coal of commercial importance. To discuss all of these would lead this chapter into needless detail. One general principle should be kept in mind. The coal areas first developed and most extensively operated are not always the best seams. Shipping facilities must control mining operations. An important factor in the cost of coal when it reaches the consumer is freight. Railroads or water routes connecting the mines and the consumer make it impossible to operate other coal areas, which do not have these shipping facilities. For this reason, the early mining operations in Ohio were partly confined to areas containing the relatively poor coal.

The Pittsburgh coal seam exists in a few counties of the state. This is the most famous horizon of coal in the Appalachian region. It is worked in Belmont more than in any other county; Jefferson perhaps ranks next. To some extent, the Pittsburgh coal is mined also in Harrison, Noble, Guernsey, Washington, Monroe, Morgan, Athens, Meigs and Gallia counties.

The Pomeroy coal, which lies from 20 to 55 feet above the Pittsburgh coal, is worked in Meigs, Gallia and Lawrence counties. While this horizon may be located in a few other counties, it is of no practical importance.

Meigs creek coal, 80 to 100 feet above the Pittsburgh, has been mined in Belmont, Harrison, Monroe, Washington, Noble and Morgan counties. It exists also in Jefferson and Guernsey, and in the latter county has been worked a little at one point.

The Clarion coal seam attains much importance in Vinton,

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[24] *Geological Survey of Ohio*, vol. vii, (1893), p. 268.

Jackson, Lawrence and Scioto counties. It is found also in Gallia county, but not in a commercial thickness.

The Lower Kittaning coal is not of much importance, though it is worked at a few places. Its best development is found in Lawrence and Jackson counties. Through Vinton and Hocking, this seam is very thin, but is mined to some extent in Perry County. In Muskingum County, near Zanesville, it is worked in a small area. Through Coshocton, this seam has a slight development. It is worked in only one township, Sandy, of Tuscarawas County. In the southeastern part of Starke County, the Lower Kittaning is mined. In Columbiana, its best development is found at Leetonia where it has been used satisfactorily for coke. While occuring also in Mahoning and Jefferson counties, it is of slight importance.

From Lawrence to Columbiana County, across the state, the Middle Kittaning appears. Its most important area is the Hocking Valley field. In Muskingum County, this seam runs from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet of good coal. One bed in Coshocton County measures five feet thick. This horizon of coal is of much less importance than the Lower Kittaning.

In one mine of Lawrence County, in Symmes township, the Upper Freeport coal appears as a four-foot seam. This horizon is not of much account anywhere across the state. Possibly, with better arrangements for shipping, its exploitation may proceed. At present, however, the best deposits are worked in the vicinity of Cambridge.

Geography of Ohio in Pennsylvanian period. By consulting a map which embraces the findings of Prof. Charles Schuchert on the question of land and water areas during the late Pennsylvanian period, in North America,[25] you will note that the western and northwestern parts of Ohio were then dry land, and that an arm of the interior sea extended eastward and northward through Kentucky and southeastern Ohio into Pennsylvania. This was a bay through which there does not appear to have been a direct movement of sea water. The fossils and plants found in the Pennsylvanian rocks indicate a variation from brackish to saline conditions in this bay.

About the margins of the ocean the land was low; extensive

[25] *Bulletin Geological Society of America,* vol. xx, (1910), plate 84.

swamps existed. The coast was not regular, but arms of the sea alternated with peninsular-like projections of the land. Between these areas of land a swamp condition existed. These flat marshes sometimes gave place to deeper water, as the coast, or as the land drainage, shifted. When this happened, vegetation was killed by the sediments brought into the water. As the shallow condition was again produced, the proper habitat for plants appeared, and the marsh condition once more prevailed. If, for any reason, the depth of water became sufficient, sea life appeared, and their calcareous remains developed limestone. Thus, we have in the rocks of this period two forms of sediment, organic and clastic; the two types of the organic, plant and animal. It should be borne in mind that on all sides of these bays or arms of the sea, this condition prevailed. Obviously, then, the area of the bay progressively decreased. The time finally came when the bay was converted into one great marsh, representing some eight thousand square miles, the area of the Pittsburgh coal seam.

The origin of coal. All are agreed on the plant origin of coal. It is further generally understood that where the coal is found now, there the plants grew. In a few cases, the coal may represent the assembling of plant remains by streams; wherever this happened, the fact is seen in the macerated condition of the plant remains.

Coal seams almost invariably overlie clay beds which contain rootlets of the plants that made the coal. This is usually termed fire clay. It probably represents the soil in which the plant growth started. Tree stumps, in an upright position, are also found associated with coal seams. Coal seams contain fossils of plants, embodying practically all parts of the organisms, leaves, fruits, bark, pith, wood, and, as seen under the microscope, spores. It is very seldom that any one plant exists so completely in the fossil form as to show all of these parts.

Many people understand that there was only one coal-making period in the earth's history. This is a mistake. During several of the geologic periods coal beds were formed. We have every reason to believe that coal beds are being formed even to-day; and this possibility aids us in unraveling the conditions that must have obtained during the Pennsylvanian period, the greatest of the coal making periods. In many parts of North America swamps with abundant vegetation may be studied now. Along the Atlantic coast the combined area of swamps is approximately 20,000 square miles.[26] The everglades of Florida and the Dismal Swamp section a little north are the most extensive of these coastal swamps. In these places, vegetation is luxuriant, and as it passes from one generation to another the remains do not decay as plants decay under the atmosphere. It is a common observation that any form of wood lasts longer when kept moist or kept entirely under water. Fence posts will rot completely off above the ground and show very little decay underneath. This slow decay of plant remains is supposed to be the first stage of making coal.

Possibly another error as to the origin of coal is the prevalent idea that our coal beds represent great forests of ferns, palms, and other tropical vegetation. While vegetation of this type would furnish more quickly the amount of vegetable matter necessary to make coal, at the same time it is more probable that the lower forms of plant growth contribute more largely to the coal seams. Certain mosses which thrive at the present time in cool, moist climates appear to produce peat more rapidly than do the higher forms of plants. This is true to such an extent that it is customary to speak of peat as the product of sphagnum moss. "Under favorable conditions a foot of peat may accumulate in ten years or even less but the usual rate is probably much slower."[27] In Alaska, in many of the northern states, and through parts of Europe, and even in Ohio, peat has been forming in recent geologic times, and these swamps are still growing.

The swamp areas, bordering ocean basins, lie in tracts that are slightly above sea level. A study of the succession of deposits in the coal horizons suggests a similar relationship of the land to the sea. A delicate balance always exists between water level and swamps. While most plants that grow thus luxuriantly require permanency of moisture, at the same time a slight over-supply of moisture checks growth. Any changed relationship in the attitude of land areas to surrounding oceans is observed first along the borders. Therefore these marshy tracts may be submerged by land movement, the vegetation checked, and the swamp become a basin in which sediments are being deposited. Without any further tilting that would tend to deepen the water, the sediments in time make it sufficiently shallow for the marsh plants to again spread. The period of deep water is indicated by the clastic bed of sand or conglomerate, overlying the coal bed. The recurrence of swamp conditions is indicated by another coal seam. Again, the manner in which coal seams converge, when worked laterally, is another evidence of the alternation of swamp and sedimentation conditions.

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[26] N. S. Shaler, *Geographic Monographs* (1895), "Beaches and Tidal Marshes of the Atlantic Coast," p. 159.

[27] Chamberlin and Salisbury, *Geology*, vol. ii, (1906), p. 571.

During the Pennsylvanian period, it is supposed that the land areas in general were low, and that they were bordered by wide tracts of shallow water. The conditions of climate appear to have favored the growth of plants. That plant growth was not exactly analogous to the tropical vegetation of to-day, is inferred from a study of the coal itself and the fossils preserved in it. Outside of the Mangrove swamps of Florida, we do not, at present, have any large trees adapted to swamp habitats. The mosses and other of the lower plant forms to-day thrive best in swamp habitats.

The important factor, however, in the development of coal seams from vegetation, is the arrested decay that follows the assembling of plant remains in water or moist horizons. Beneath the water putrefaction or fermentation proceeds slowly. The oxygen is gradually given off, but the carbon is retained. The details of the change from wood to the different forms of coal are best understood by consulting the following table:[28]

	CARBON	HYDROGEN	OXYGEN	NITROGEN
1. Wood	49.66	6.21	43.03	1.1
2. Peat	59.5	5.5	33.0	2.0
3. Brown coal	68.7	5.5	25.0	0.8
4. Bituminous coal	81.2	5 5	12.5	0.8
5. Anthracite	95.0	2.5	2.5	0.0

The increasing percentage of carbon, it must be remembered, is relative. The actual amount of carbon does not gain as plants become peat, brown coal, bituminous, etc. The decrease in the amount of oxygen, through slow decay, correspondingly increases the percentage of the carbon.

Kinds of coal. The above table shows that coals are classified in accordance with their content of carbon. Sometimes coal is said to be metamorphosed wood. The conditions that bring about the metamorphism, it is urged, are quite the same as those which metamorphose any other deposits, chiefly heat and pressure. This is a subject on which little is definitely known. Between peat and anthracite there is a wide gap. The difference is chemical; it appears to be largely a deoxidation process. Just the factors that contribute to this process is the part of the question on which students are not agreed. Possibly the pressure of overlying sediments indurates deposits beneath, and induces chemical changes. Possibly, accompanying this pressure, is heat which is a strong factor in the change. The slow decay of the vegetation is due to micro-organisms, which evolve chemicals, that in themselves may induce further chemical changes.

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[28] Chamberlin and Salisbury, *Geology*, vol. ii, (1906), p. 570.

In any event, it is customary to speak of anthracite as metamorphosed bituminous coal. This explanation is given practical force because of the fact that anthracite coal is found chiefly in areas where the rocks have been very much disturbed. In eastern Pennsylvania where the strata have been sharply folded, only anthracite coal is found. In the western part of the state, where the disturbance has been slighter, the coal is bituminous. In Ohio, where there has been very little disturbance, we have only bituminous coal, and sometimes the less metamorphosed seams of poorer bituminous coal. The theory that heat appears to be connected with the change from the lower grades to anthracite coal is further strengthened by a study of coal deposits in New Mexico, where portions of bituminous beds next to igneous intrusions have been changed to anthracite.

Rank of state. Ohio is one of the older states in the production of coal. It has long maintained a prominent position, and during the year 1908 ranked fourth in both tonnage and value. Many of the coal seams in Ohio are not as valuable as others. It is to be hoped that as men learn more about the nature of coal deposits and their adaptation to different uses, the lower grades of coal may be found of increasing commercial importance. Only in the last few years have we begun to attack the question of coal scientifically. Men learned early that all coals would not coke, but they did not ask themselves why; experiment eliminated the poorer coking coals. Sometimes the efficiency of a coal is very much lowered by impurities acquired in process of mining; these, it has been found, may be partly eliminated by washing. It has been learned, furthermore, that furnaces and other arrangements for using the fuel must be varied to suit types of coal; a particular coal may have low efficiency in a furnace which will get a much higher amount of heat out of another coal to which it is adapted. The laboratory work now under way by the federal government, as well as by some of the state institutions, will add materially to the importance of the lower grade coals.

GLACIATION IN OHIO

- Introduction ... 184
    - Margin of the ice sheet
    - How this ice was formed
    - How glacier ice moves
- The work done by glaciers ... 190
  - Erosion by glaciers ... 190
    - Contrast between glaciated and unglaciated regions
    - Tools of glacier ice
    - Evidences of erosion
  - Deposition by glaciers ... 194
    - Simplest condition of glacial accumulations
    - More complex conditions of a continental ice sheet
    - Terminal moraines, retreatal moraines, morainic loops
    - Glacial deposits in valleys
    - Outwash plains
    - Eskers
    - Valleys leading away from the ice
    - Lake deposits
  - Effects of glacial action ... 199
    - When relief is increased
    - When relief is decreased
    - Glacial topography
    - Drainage changes
- Cause of glacial period ... 202
    - Former high altitude of continent
    - Change in position of the earth's poles
    - Change in eccentricity of the earth's orbit
    - Variation in content of the earth's atmosphere
- Complexity of the Pleistocene glacial period ... 206
    - Pleistocene stages
  - Other glacial periods ... 207
    - Evidences of earlier periods
    - Proterozoic glaciation
    - Cambrian glaciation
    - Permian glaciation
    - Conclusions
- The glacial deposits of Ohio ... 212
    - Glacial lobes in Ohio
    - Ice lobe margins
  - Ice front lakes ... 214
    - Lake Maumee
    - Lake Whittlesey
    - Lake Warren

The origin of Lake Erie 217
Lakes in general
The St. Lawrence drainage basin in preglacial times
Local warping
Glacial erosion
Old shore lines in Ohio 224
Origin of shore lines
The development of cliffs
Beaches
Along-shore currents
Under-tow
Bays
Other shore line structure
Geographic influences
Post-glacial tilting

INTRODUCTION

In many of the northern states and much of Canada, one cannot get away from the evidences of glaciation. It has been estimated that the area of the continental glacier was 4,000,000 square miles. No page in the geological chapter is plainer, yet students were very slow in reading it correctly. Of all the evidence, the most striking, perhaps, is the presence, in an area of organic and clastic rocks only, of scattered bowlders of crystalline rocks. We sometimes call these "erratics," sometimes "nigger heads." Early the question was asked, how did they come here? But for a long time the question was not correctly answered. Most students who gave the matter any attention said that they were dropped from the bottom of icebergs that floated about over the lands when covered by floods, possibly the floods of Noah's deluge. Then other curious phenomena were noted: Broad rock surfaces were seen to be striated and grooved. At first it was said that these markings only showed where icebergs, shod with stones, had bumped along across the shallow parts of the seas. But how could this make the markings so parallel, it was asked, and why did the striae always have such a uniform direction? These were indeed puzzling questions, but not too severe for those of much orthodoxy and little reason. Again, men noted mounds of heterogeneous material, large and small stones, stones of many varieties. These tumuli were sometimes in the lower places, often on valley walls, and sometimes on the highlands between valleys. Streams, it was well understood, deposited gravel and silt, which would be found only where streams had been..

In time all these puzzling observations came to be understood. Now, within the area that was glaciated one seldom meets a citizen who has not some knowledge of the glacial period.

Margin of the ice sheet. Nearly three-fourths of Ohio was covered by the ice sheet. The front of the ice coincided roughly with the rugged topography of the coal regions. On the eastern border of the state, the glaciated area terminates about ten miles north of East Liverpool. Its margin runs almost directly west to Canton; thence it has a southwest direction to Millersburg, in Holmes County. From Millersburg, the ice began to turn more nearly west, to approximately the eastern border of Knox County. From this point, for several miles, the general front of the glaciated area has a north-south direction. But upon entering Perry County, it again bears to the southwest, crossing the Scioto River near Chillicothe; from Chillicothe the same general direction continues to the Ohio river, in Brown County. From this point westward, nearly to Cincinnati, it reaches a few miles into the area of Kentucky.

This glacial boundary in Ohio is but a segment of the margin of the great ice sheet that covered so much of North America. In the western part of the Mississippi basin, the general front had a northwest-southeast direction, except near the Rocky Mountains, where it trended more nearly east-west. About one-third of Montana was ice-covered. The southwestern corner of North Dakota was beyond the ice sheet, and the western half of South Dakota was not glaciated. From this point, the front of the glacier bore almost directly south, covering the eastern end of Nebraska, then turning to the east; only a small area of the northeast corner of Kansas was glaciated; thence the ice margin bore slightly south of east, crossing the Mississippi River a few miles north of Cairo, Ill. In southern Indiana, a triangular shaped area, its base following the Ohio River north to Madison, was not glaciated; a short distance north of Madison the ice crossed the river; thence, its front trended slightly north to the vicinity of Cincinnati.

The northwest corner of Pennsylvania is also included in the glaciated area, the ice-front passing northeastward into New York State; it shortly bears southward again, leaving New York

State near Olean. From this point, towards the Atlantic, the ice margin had a southeasterly course, crossing the Susquehanna River a few miles south of Wilkesbarre; thence the ice trended more nearly east. The Delaware River was crossed in the vicinity of Easton, Pa.; and the ice-front bore eastward from New Jersey, just south of Staten Island. A sharp moraine extends the entire length of Long Island, but the ice sheet may have reached farther south. From this point eastward, the margin of the glacier cannot be determined. It is certain that all of New England was glaciated, and it is thought either that the ice extended into the area where the Atlantic now is, or that the shallower part of the ocean, bordering New England, was then land on which the ice sheet terminated.

Whether all of British America was covered by this same great ice sheet, is not definitely known. It is supposed that Labrador was entirely glaciated, and that the area from Hudson Bay westward into the Mackenzie valley was also covered with ice. But, west of this river valley, it appears that the ice belonged to the high altitudes of the Rocky Mountains, that is, the Rocky Mountains in British America were covered by a different sheet, a sheet of local origin. All of the other parts discussed were covered by a continuous ice sheet.

How this ice was formed. We are acquainted with the ice that forms on the surface of our streams and lakes, but glacier ice did not originate in this way. An appreciable thickness of water may be frozen in a short time. Such ice differs very much from glacier ice. No one has demonstrated exactly how glacier ice is made; laboratory facilities cannot be arranged to give an object lesson in this. Snow may be turned into a form of ice by pressure; a mass of snow, a névé field, through continuous accessions, will develop sufficient pressure, by its own weight, to change the snow crystals into granules. This first change produces what is called granular névé. In the gathering areas of the Alpine glaciers, névé fields have been studied. Further pressure through increasing weight changes this granular névé into glacier granules, small round bodies of ice. Later these granules form glacier ice.

It is impossible to reasonably approximate the weight or the volume of the ice sheet that covered so large a portion of North America. It is known that high mountains in New England were completely covered; that southward of the broad basins now occupied by the Great Lakes the ice pushed far into the Allegheny plateau; and that in the Mississippi valley, where no great heights exist, it expanded so far to the south that its mass must have been great. Men have attempted to estimate the thickness of this sheet in particular places by studying the slope of the ice front. It has been found that where the margin of the ice front was registered, by accumulations of drift against the sides of the valley, for example, it had a certain decline. By carrying this same slope northward, one gets a suggestion, at least, of the thickness at any given distance to the north. Such a study has assigned astounding depths to the ice, so great that one concludes that this method is not reliable. The fact that the ice sheet had a certain length in the Mississippi valley, and that it moved outward from a given place, would warrant the conclusion of great thickness over part of the area beween these termini.

How then was so much ice made? This is a question on which much has been written. The simplest explanation assumes a heavy and regular annual snowfall, with little or no melting. If this form of precipitation were to continue a sufficient length of time, and little of it were to be melted, eventually an ice sheet sufficiently great to cover any continent might result. But such an explanation hypothecates a condition which, we all believe, never existed. We have to-day some small areas of continuous ice: one about the south pole, the other covering most of Greenland. In both of these areas there is neither continuous snowfall nor an absence of melting. Man knows of no altitude so high that the ice which forms there does not suffer from some melting. It wastes even when the temperature is continuously below zero. The essential prerequisite for the development of ice fields is that precipitation, in the form of snow, should exceed the wastage. However small the increment left over from each warm season, if this relationship of snowfall and melting continues long enough, an ice sheet will result.

A study of the glaciated parts of North America, omitting the Rocky Mountain region, points to two centers in Canada, away from which the ice moved. One center lies east of Hudson bay, in Labrador; the other is west of Hudson bay, in the Keewatin district. In these areas, for perhaps thousands of years, the prevalent form of precipitation was snow; in both, at first, only slight bodies of snow endured from one year to another. Gradually the mass of snow increased, and by its own pressure the lower parts were changed to granular névé. With the increments of later seasons, granular ice was formed; with continued snowfall, this moved laterally as glacier ice.

How glacier ice moves. Should you visit a valley glacier of Switzerland you would find in its névé field evidences of growth, while at the lower terminus of the glacier you would see evidences of wastage. Between these two points the valleys generally have a marked slope. The question of motion does not here appear to be complex. Ice, we all know, is not a solid; a block of it, when supported only at the ends, sags in the middle of its own weight. The movement of these valley glaciers is so obvious and so natural that they are sometimes called ice rivers. It is immaterial how deep they may be; a tongue of ice in a valley, which slopes away from a mountainous area, should move.

But when we think of a great continental glacier, covering thoussands of square miles in one continuous sheet, we cannot find the same reasons for motion. Motion in Alpine glaciers appears to be largely a matter of gravity, and yet the process is not the same as the motion of a cable, which is being fed through an inclined conduit, or what occurs at the lower end of an inclined plane, already filled with ice blocks, when we add another block to the upper end. While there is movement in these Alpine glaciers and in the ice sheets, they do not appear to move as a unit; the motion is not so simple. The gathering or dispersion center of an ice sheet is its place of growth, the margin, its place of decay. When the margin remains stationary, as well as when it advances, a forward motion must prevail in the ice, back to the dispersion area, and this in spite of a prevailing temperature below the melting point.

Ice is a mineral; when forming, the molecules arrange themselves according to the hexagonal system of crystals. When snowflakes are piled up, these crystals are bent of their own weight, crowded together, interlocked, and they suffer some melting. It is thus that the structure of névé becomes granular, and the individual granules grow. By experimentation, it has been proved that these granules grow under all conditions of temperature. We all know that in crystal growth great pressure is exerted; thus, jars are broken when water freezes in them. The expansion causes pressure, and because of pressure, great tension must exist in every ice area. Physicists teach us that heat is an accompaniment of pressure. It has been determined that when the pressure evolved in a growing mass of ice equals one atmosphere, the heat equivalent is to 0.0075° C. Students now believe that in masses of ice, either of the Alpine or Continental glacier type, there is constant melting and almost immediate refrigeration of tiny particles of ice and water, resulting possibly from pressure and constant tension. If this is true, the units, either crystals or granules, in an ice sheet must be almost constantly in motion.

At the heads of glaciers, where motion is initiated, there may be great downward pressure, but not vigorous thrusts from behind, and probably only moderate thrusts developed within the body itself. There seems, therefore, no escape from the conclusion that the primal cause of glacial motion is one which may operate even under the relatively low temperatures, the relatively dry conditions, and the relatively granular textures which affect the heads of glaciers. These considerations lead to the view that movement takes place by the minute individual movements of the grains upon one another. While they are in the spheroidal form, as in the névé, this would not seem to be at all difficult. They may rotate and slide over each other as the weight of the snow increases; but as they become interlocked by growth, both rotation and sliding must apparently encounter more resistance. The amount of rotary motion required of an individual granule is, however, surprisingly small, and the meltings and refreezings incident to shifting pressures and tensions, and to the growth of the granules, seem adequate to meet the requirements. In order to account for a movement of three feet per day in a glacier six miles long, the mean motion of the average granule relative to its neighbor would be, roundly, $\frac{1}{10000}$ of its own diameter per day, or one diameter in 10,000 days; in other words, it would change its relation to its neighbors to the extent of its diameter in about thirty years. A change of so great slowness under the conditions of granular alteration can scarcely be thought incredible, or even improbable, in spite of the interlocking which the granules may develop. The movement is supposed to be permitted chiefly by the temporary passage of minute portions of the granules into the fluid form at the points of greatest compression, the transfer of the moisture to adjoining points, and its resolidification. The points of greatest compression are obviously just those whose yielding most promotes motion, and a successive yielding of the points that come in succession to oppose motion most (and thus to receive the greatest stresses) permits continuous motion. It is merely necessary to assume that the gravity of the accumulated mass is sufficient to produce the minute temporary liquefaction at the points of greatest stress, the result being accomplished not so much by the lowering of the melting-point as by the development of heat by pressure.

This conception of glacial "flowage" involves only the momentary liquefaction of minute portions of the mass, while the ice as a whole remains rigid, as its crystalline nature requires. Instead of assigning a slow viscous fluidity, like that of asphalt, to the whole mass, which seems inconsistent with its crystalline character, it assigns a free fluidity to a succession of particles that form only a minute fraction of the whole at any instant.

This conception is consistent with the retention of the granular condition of the ice, with the heterogeneous (in the main) orientation of the crystals, with the rigidity and brittleness of the ice, and with its strictly crystalline character, a character which a viscous liquid does not possess, however much its high viscosity may make it resemble a rigid body.[1]

THE WORK DONE BY GLACIERS

There are two methods of determining the work done by the continental glacier. We may study ice masses in existence today. Glaciers of the Alpine type are found on every continent. Greenland, an island 512,000 square miles in area, is almost entirely covered with ice; this is an ice cap, and approximates a continental glacier. In Antarctica there exist extensive ice areas, while in Alaska there are many splendid examples of the Piedmont or Malaspina type of Glacier. Relative to their size, these glaciers give many suggestions of the work that the continental glacier, such as once covered our part of North America, must have done. Another method of unraveling the activities of the ancient ice sheet is to study the evidences which it left. It made great accumulations of drift, it has worn and polished rock surfaces, has carved deeply elsewhere into the rock, has silted up river valleys leading away from the glaciated areas, and has produced complex soils, by bringing together material from distant parts.

The glaciers now in action are tearing away and building up. So far as we can determine, the glaciers of the past did the same. Glacial work consists of erosion, transportation and deposition. Sometimes these factors appear to be of equal weight. In other areas, one or the other is in the ascendant. Naturally erosion and deposition are opposed, and cannot be in operation in the same place at the same time.

EROSION BY GLACIERS

A country once glaciated always bears the scars of icework. No other natural agencies derade and aggrade just as glaciers do.

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[1] Chamberlin and Salisbury, *Geology,* vol. i, (1905), pp. 299–301.

Rivers cut rock, heat and cold crumble it, chemicals disintegrate it, tool-laden winds scour it, lightning may rive it, and earthquakes disrupt it, but never is the effect that of glacial action.

Contrast between glaciated and unglaciated regions. In countries where glaciers have never scoured, we find the bed rock covered by a mantle of residual soil, the thickness of which depends upon a great many conditions. But where a glacier has moved over the area, this residual material is largely, if not entirely, wanting. Valleys in an unglaciated region are narrow or flat, according to their age. When narrow, their cross-section is like the letter V; when broadened by age, the sides of the V are more flattened. Broad, unglaciated valleys have smooth sides, the slopes are continuous and uninterrupted; a view through such a valley shows interlocking spurs, the inheritance of a natural tendency of streams to swing. In an unglaciated area the surface reflects the texture and attitude of the rocks; shoulders and escarpments mark the harder horizons. From cliffs of a hard ledge, overlying a softer horizon, continued weathering removes great blocks which come to a temporary position of rest on the slope below. Accentuated weathering along closely assembled joint planes carves the ledges into columns and pillars, which sometimes are isolated as great stacks and spires. The hills and mountains of unglaciated countries have uniform outlines, except when folding has tilted the layers; then the harder beds break the otherwise even slopes.

Should such an area as the one just described be glaciated, either the valleys would be buried, or their cross sections would be so altered that they would resemble more nearly the letter U. If the valleys were transverse to the direction of glacial motion, in all probability they would be largely filled with drift; if parallel to glacial motion, they would be plowed out and their profiles would be changed. The ice, feeding through these valleys, would wear off the ends of the interlocking spurs. Instead of having continuous slopes, near the axis of the valley the slope would be oversteepened, while farther up, it might be made irregular by deposits of drift. The cliffs and other evidences of differential rock weathering would be partly or entirely obliterated through glacial scouring and plucking. The remnants of weathering, such as spires, stacks, and detached blocks on slopes, would be removed. The hills would no longer have uniform outlines, but would be worn away more on the stoss side, the side approached by the ice. Mountain slopes would be broken through localized ice action, and the mountain tops would be rounded. There would be very little residual soil left. Rock areas, where not covered by drift, may show the effects of glacial scouring, either in smoothed, striated, or grooved surfaces.

Tools of glacier ice. Clear ice never abrades rock surfaces, any more than water, without tools, erodes the beds of rivers. But glacier ice acquires tools readily. As it first moves into a country, it finds a great mass of residual and loose rock. This material is gradually worked into the ice and held as tools, to rasp all surfaces against which the ice moves. After the residual soil has been removed, the acquirement of a further load is an easy task. Man has never yet gone so deep in the earth that he has not found the rocks broken by joints and faults. These divisions make it easier for rivers and ice to remove blocks. This is especially true when ice moves through a valley or around hills and mountains. The great bowlders, sometimes weighing many tons, scattered over the states, were brought from areas north, probably from the slopes of valleys or the sides of hills.

Furthermore, effectiveness of glacial erosion depends directly on the hardness of its tools. Some rocks are so soft that they can accomplish very little abrasion, even against the same kind of rock. The size of the tool is of slight importance. A grain of sand, will probably wear rock beneath the glacier more than would a slab of shale weighing many pounds, because quartz is very hard. The erosion accomplished by a glacier is not entirely on its bed. The rock which is taken into the basal parts of a glacier is raised from one level to another, through the buckling and shearing of the ice; the material may ascend even to the surface of the glacier. Consequently much mutual attrition of block on block tends to wear the tools in transit. Streams issuing from glaciers bear heavy loads of exceedingly fine material, partly produced by this mutual attrition.

Evidences of erosion. The most universally convincing proof of the power of glacier ice to wear rock is seen in a surface that bears striae, grooves, or gouges. Such a surface merely shows a stage in glacial eroson. It is by the continuous removal of the rock, in registering even delicate scratches upon it, that hundreds of feet of solid rock have been gradually rasped away from the bottoms of valleys in some localities. Sometimes, along the sides of a valley, a block will be plucked bodily; but the slow scouring and rasping process, such work as the glacier did last on a striated surface, is the more usual method of wearing away rock.

The fiords of Alaska and Norway, the U-shaped valleys of Switzerland, the rock basins now holding lakes in England and Scotland, the over-deepened valleys in the Finger Lake region of New York, the cirques and amphitheaters of all glaciated mountainous areas, show the competency of ice to erode rock. There may be a lack of agreement among students as to just how fiords and rock basins were produced. In the studies of Gilbert in Alaska, of Penck, Brückner, and Davis in the Swiss region, of Reusch in Scandinavia, of Marr in England and Scotland, of King and Atwood in the Rockies, of Chamberlin and Salisbury in Greenland, and of Tarr and others in central New York, we have an array of evidence that takes the question of glacial erosion out of court. It is no longer a discussed point.

The conditions that obtained in the regions where active ice can now be studied are not necessarily identical with the erosion processes of the ice sheet in North America. The closest example, perhaps, is found in Greenland, where a valley leading to tide level now bears a tongue of ice, behind which is a large area of ice whose forward movement is concentrated on this one valley as an outlet; erosion consequently is vigorous. In all of our over-deepened valleys, fiords and basins, it is probable that ice action was similarly concentrated. Such a tongue of ice, shod with tools, slowly rasping the bottom and the lower side walls of the valley, and continuing in action through many centuries or perhaps thousands of years, did not accomplish anything astounding, in wearing away the rock many hundred feet. In addition to lowering the bottom of the valley, its walls were cut back, thus changing its cross-section to a broad U. Tributary streams that formerly met the major stream of the valley at grade were left hanging several hundred feet. "The hanging valley is especially significant in two lines of physiographic interpretation. It is a conspicuous earmark of the former presence of glaciers; and it helps to a conception of the magnitude of the Pleistocene glacial erosion."[2]

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[2] Harriman Alaskan Expedition, vol. iii, (1904), *Glaciers and Glaciation*, page 115.

DEPOSITION BY GLACIERS

Glacial deposits are always heterogeneous in material, and usually so in texture and structure. The word "drift" includes all débris transported and deposited by glaciers or streams issuing from glaciers. "Till" refers to the deposits made directly from the ice. The material assorted by glacial waters is called "modified drift." The designation "drift," therefore, includes the other two.

The simplest condition of glacial accumulations. The earliest terms used in reference to the accumulations of glaciers referred particularly to valley glaciers. Valley glaciers carry along their sides much material rasped from the walls of the valley. At their ends, where melting takes place, the débris not carried away by the outwash stream accumulates, forming a "terminal moraine." The deposits that gather along the sides or margin of a glacier are called "lateral moraines." When one valley is tributary to another and a glacier occupies each, the two lateral moraines, below the point of coalescence, unite, forming in the single glacier stream a "medial moraine." These three designations for moraines are the earliest and best fixed in the literature. Unfortunately, their limited use has given rise to much misconception in America, where only a fraction of the ice deposits was made by valley glaciers.

The more complex conditions of a continental ice sheet. The deposits made by a continental glacier are of a very complex origin. The drift which we study to-day, in most of the states, was left by the retreating ice sheet. This retreat was slow. All the conditions of melting and drainage along its front merely repeated conditions that obtained while the ice sheet was expanding. If, after the continental glacier had attained its maximum growth, the conditions that induced glaciation had suddenly ceased to operate, and all of the ice had melted in situ, as an exposed block would melt on the sidewalk, the glacial deposits made would be simple. A terminal moraine accumulated as often as the advancing ice sheet held a stationary position for any great length of time; when the glacier advanced further, this moraine was subject to ice erosion. For this reason, much of the moranic material, which accumulated as the ice sheet was spreading out over the country, was altered. For this reason, the drift that we study to-day represents for the most part the deposits made by the retreating ice sheet.

Definite ice halts are registered by bands of thickened drift; the country between such morainic bands also bears drift called "ground moraine," The bands of drift are built up where ice wastage and ice feeding are approximately equal. If, in a year, the front of the glacier is wasted 1000 feet, and the onward movement of the ice sheet during this time is also 1000 feet, its margin remains stationary, and the débris in that thousand feet of wasted ice is deposited at the margin. If the feeding of the ice is slightly less than the wastage, the margin retreats slowly and the débris is accumulated in a wider ridge or band. We sometimes have morainic bands several miles wide. These represent marked wastage of the ice accompanied by almost as active feeding.

It has been established that a continuous advance did not characterize the precessional movement of the glacier; nor did a constant retreat mark its recession; instead, oscillations took place at many points along the margin. For several seasons the front of the ice may have held a nearly constant position; then, during succeeding years, the ice growth being greater than the ice decay, the margin advanced, riding over and eroding deposits just made; or, the wastage being much in excess of the feeding, a corresponding retreat resulted.

Terminal moraines, retreatal moraines, morainic loops. The farthest advance of any particular ice sheet is marked by the terminal moraine of that epoch. Other positions of the margin, lying iceward of this extreme position, are marked by "retreatal" moraines. All bands of drift between the terminal moraine and the dispersion centers of the ice are retreatal moraines. Small basins and valleys were occupied by lobes and tongues of ice. Along the front and sides of these lobes and tongues débris accumulated, forming morainic loops. Morainic loops are details of retreatal and terminal moraines.

The margin of a continental glacier is always irregular, if there is any appreciable relief in the country which it covers. The movement of the glacier is retarded by increasing altitudes; it moves onward freely into valleys or basins of lower altitudes. Our continental glacier, extending as it did quite across the whole continent, met a great variety of relief. Through the basin of the Mississippi, the ice advanced most easily and extended farthest.

The Appalachian mountains and bordering Allegheny plateau impeded its progress; consequently, the margin of the ice eastward of the axis of the Mississippi valley had a northward trend. These large physiographic provinces gave the glacier its general outline, while local topography caused the minor irregularities of the margin. Parts of the Allegheny plateau are dissected by north-south valleys. This condition is noted in central and western New York. These valleys produced in the ice-front a very dentate outline. During both the progress and the retreat of the glacier, each valley was occupied by a tongue extending several miles beyond the main ice mass. The plateau parts of Ohio are also irregular in relief. Where its valleys were coincident with the direction of ice motion, tongues and lobes extended into them, and often moved many miles beyond the ice sheet proper. The Grand River valley, the Scioto, and the Miami, each caused a lobation in the ice front. Slighter valleys, contiguous to these, caused minor details along the margin of these lobes. The retreatal moraines and smaller loops enable us now to decipher the value of this topographic factor in reconstructing the outline of the ice-front.

Glacial deposits in valleys. Valleys contiguous to the ice front always carried a great supply of water. If the valley sloped away from the ice, this water flowed off. If the valley sloped towards the ice, the water gathered, forming a lake which continued to deepen till an overflow somewhere about the border of the valley was discovered. Under the former condition, the valleys now usually bear heavy deposits of outwash material, which has been progressively terraced during and since glacial times.

When a speedy retreat followed a stationary position, maintained a long time by the ice, morainic terraces were left along the valley slopes. Where, on account of minor irregularities in the valley wall, local bodies of water gathered, the drift accumulating in them was prevailingly washed and stratified. When gravel and sand prevail in these deposits they are called "kame terraces."

If, in a valley, the ice became less active and some portion of it was left stagnant, later stream deposits might completely bury all or part of it; such a buried block of ice would melt slowly; possibly hundreds of years elapsed before all had disappeared. The position of a detached mass of ice is to-day indicated by a basin called a "kettle hole;" when containing water, a "kettle lake." Modified drift, and, less frequently, kettle lakes, characterize kame areas.

Whenever a tongue of ice stood for a long time at a given point in a valley, its sides and front were marked by a morainic loop. The streams issuing down through the valley from this position were heavily laden, and in consequence aggraded the valley floor for several miles beyond. The washed deposits thus accumulated down stream from a morainic loop are called "valley trains."

Outwash plains. The intervalley portions of retreatal moraines are often bordered by gradually sloping bands of gravels and sand called "outwash plains." The material of these plains was deposited by streams or sheets of water issuing from the ice-front. Local irregularities of relief in this intervalley area introduced corresponding irregularities in the shapes of these outwash plains. The genesis of valley trains and outwash plains is practically the same, except that the former deposits are confined laterally.

Eskers. Sometimes in the thinner areas, near the front of the ice sheet, surface water may be directed towards a crack or opening in the ice, and then flow along beneath the glacier to its margin. This condition could not exist if the ice were very active; it obtains only in stagnant or semi-stagnant ice areas. Streams gathering on the surface and flowing into a depression to the bottom of the glacier carry with them much débris. They also continue to transport material as they flow beneath the glacier. In reference to carrying a load, subglacial streams behave just as do surface rivers; they aggrade and erode. As they aggrade their beds, the stream itself is lifted against the arch above and tends to melt the ice further. This process continuing, the channel becomes more aggraded, and the size of the arch gradually grows. At the mouth of the channel, that is, at the glacier margin, finer materials, which the stream was able to carry through, are deposited. Sub-glacial streams, in one respect, differ from surface rivers; they may flow up hill. This is possible through hydrostatic pressure. Water accumulating on and beneath the ice may form a reservoir of sufficient volume to give pressure that will lift a stream over a considerable altitude.

The courses of these streams are indicated to-day by the long sinuous ridges of washed drift. The outline of these ridges shows the shape of the ice arch that once was above them. Their vertical range defines the irregular grade of the sub-glacial stream. Ridges of this origin are called "eskers." They usually have a serpentine course; and because they consist almost entirely of washed deposits, they were formerly called "serpentine kames." In general shape and sometimes in position, they resemble morainic loops, but can be easily distinguished by examining their material.

Valleys leading away from the ice. In some parts of the country, ice-borne material is found hundreds of miles south of the margin of the continental glacier. The Delaware, the Susquehanna, and the Ohio rivers carried outwash from the ice sheet, far to the south. In this state, the Muskingum and its various tributary valleys, the Scioto, the Hocking, and the Miami river valleys, are flood-plained and terraced by waters that issued from the glacier. The abundance of this outwash, and its great distance from the margin of the ice, furnish convincing proof of the turbulent condition of streams that flowed from the ice sheet.

Lake deposits. The drainage from glaciers does not always flow away freely. When the land slopes towards the ice front, the water accumulates. If the area is a plain, the resulting lake will be long, with its greater axis parallel to the ice margin; if the area is a valley, this axis will be transverse to the ice margin. The depth of such a lake depends upon the altitude of the outlet which eventually its waters will find. The present-day evidences of these former lakes is dependent upon their duration; the longer a lake stood at a particular level, the more sharply developed became its shorelines. The duration of ice-front lakes is contingent on the time during which the ice held its stationary position. Some lakes that bordered the front of the recessional ice must have endured for many centuries; others were relatively evanescent.

In nearly all respects, these ice-front lakes were like the lakes of today. Rivers flowed into them, bays varied their outlines, winds made waves on their surface, currents doubtless existed, just as in the Great Lakes. Cliffs were cut by wave work, and beaches constructed. At the mouths of rivers, deposits accumulated as deltas. Spits, bars and cusps varied the shoreline. Away from the shore, fine material was deposited as lake clay. But, in these lakes, the quantity of clay was greater than in non-glacial lakes; along the entire margin of the ice, which always formed a part of the shoreline, débris gathered from the wasting glacier; this contained much fine clay, which was disseminated in suspension through the lake, gradually settling to the bottom. For this reason, clay is found more commonly on the beds of glacial lakes.

These lake deposits have been exposed to weathering since glacial times. This interval is variously estimated as from ten to forty thousand years. However long it really is, weathering has spared to an amazing degree the work of the glacial lakes. Their old shorelines, with interesting details of structure, in addition to the cliffs cut in enduring rock, stand out conspicuously to-day. Their deltas, creased, to be sure , by gulleys and streams during the post-glacial time, still bear their original outlines. The locally thick mantle of lake clays has sometimes slumped into corrugated ridges, but is always easily recognized. The islands that often dotted the ice-front lakes are encircled by cliffs and beaches; those near the shore were tied by bars, which cannot escape one's attention even to-day. Their overflow channels now are frequently only fossil river-valleys. No phase of glacial history inspires greater zest in investigation.

EFFECTS OF GLACIAL ACTION

Usually there is no difficulty in distinguishing a glaciated from a non-glaciated region. Normally, a country's surface is made irregular by rivers and other weathering agents; but while that country is buried beneath an ice sheet, these agencies cease to act. The rasping and aggrading effects of a continental glacier tend to decrease the irregularities of pre-glacial topography. Eminences are smoothed out or rounded. Broken slopes are usually made more regular. Minor depressions are frequently filled with débris. Thus, the usual effect of glaciation is to decrease surface irregularity. At the same time, glaciers often increase the relief. The extent of smoothing, and of giving added relief, depends somewhat on the rock texture and structure of the region. Easily eroded rocks suffer most from glacial action. When hard rocks do not exist in the area itself, or in its immediate environment, the glacier is not supplied with effective tools for erosion.

When relief is increased. Glacier ice cuts deep only when its erosive powers are concentrated. Whether a given area under glaciation will come out with increased or diminished relief, therefore, depends upon its topography preceding glaciation. If it already bears a pattern into which the ice fits as it moves, the relief of that pattern will be increased. Such is the case when the country has valleys trending in the direction of the ice motion.

Glacial topography. The deposits made by an ice sheet account for much of the resulting relief. Morainic bands, which mark relatively stationary positions of the ice margin, almost invariably are irregular in surface. This irregularity is partially genetic, more debris being deposited at one point than another, and is sometimes due to the erosion of waters flowing away from the ice margin. A morainic surface is always slightly irregular, and frequently has sharp relief. In valleys, the loops of drift generally form ridges. These ridges vary from a few feet to over one hundred feet in height.

The esker is another ridge which makes glacial topography irregular; as already discussed, eskers do not always follow valleys or in their direction show complete control by preëxisting topography.

Kames are mounds of prevailingly stratified deposits; these mounds frequently have intervening depressions, sometimes containing water, called "kettle lakes." Kames from 100 to 200 feet in height are not uncommon in connection with morainic bands. The size of kettle lakes and of depressions in drift areas varies much. These depressions are sometimes due to detached blocks of ice being buried beneath accumulating drift. Ice thus covered decayed very slowly. The larger the block, the larger the resulting depression. Even if no deposits were made about the block, as it was covered, a slight basin would mark its position; as it decayed much of the débris in the ice would slump down the sides of the mass, coming to rest on the plain beneath; the quantity of this débris would decrease as the block grew smaller, hence a depression would be formed. Sometimes large portions of a valley tongue, the glacier being stagnant, have been thus buried. No doubt many centuries passed before such a large mass of ice entirely disappeared. In Alaska are forest trees, growing on a soil horizon that accumulated over ice plains thus protected from decay; plants took root, and eventually trees spread over the area. No one can tell how long such a buried mass of ice may endure.

Drainage changes. The preglacial stream pattern is sometimes altered through glaciation. Fewer changes result (1) when the land drains away from the ice, but modifications are possible, (2) when the rivers of the area flow towards the ice margin. Drainage change is also possible, and no doubt often has resulted, (3) when the preglacial streams had a course parallel to the ice margin.

We know very little about the actual methods of glacial erosion. A valley may to-day bear a glacier, and in the part of the valley from which the glacier has retreated the evidence of erosion may be obvious. But no one can tell just what is going on beneath the tongue of ice. All infer that the basal part of the ice is shod with stones which, by the weight of the ice above, are held against the rock beneath, and, as the glacier slowly moves, this bed rock is worn. Probably our chief stumbling block in appreciating the erosion accomplished by glaciers is our difficulty in grasping the time involved. The history of mankind is so short that man's imagination fails him in conceiving geologic time. Primitive man shaped his tools by wearing a softer rock against a harder. Even two rocks of the same hardness may be made to wear each other out. A tiny scratch in a slab of rock removes a measurable amount of material. The entire mass of the rock is only a multiple of that quantity removed. Given time enough for sufficient repetitions of the scratch, and the rock may be worn away. No one hesitates to grant a glacial period tens of thousands of years duration. Many do not hesitate to make it hundreds of thousands of years. Even the more conservative estimate would account for such glacial erosion as we have studied, provided the ice were continuously laden with tools. It is the tongue of ice leading ahead of the main mass, through valleys, that does the great erosive work. Towards the axes of such valleys the weight of the ice trends. The depth of the valley insures this weight. The valley walls supply tools which, added to the rocks already in the ice, insure erosion. Consequently, the rock relief of the region must be increased, if the region preglacially had valleys trending in the direction of the ice motion.

When relief is decreased. The removal of minor irregularities by the general erosion of an ice sheet, to that degree decreases relief. The basins and valleys existing preglacially in the area measure its maximum relief. If these depressions are transverse to the direction of ice motion, they will not be deepened; more often they will be shallowed through the accumulation of glacial débris. The orientation of the lines of greatest relief decides whether that relief will be increased or decreased through glaciation. It is possible that the irregularity of glacial deposits, as discussed in the next section, may have greater relief than the area had originally.

Since the streams that flow from a glacier usually bear a load, one can understand how, under the first of these conditions, the valleys would be silted up with outwash material. Flood plains thus are quickly developed. If the valley concerned was already in old age, the mass of this material accumulating might locally reduce the grade of the valley floor to the extent of ponding some of its drainage. Minor changes have been thus induced.

Under the second condition, lakes are always formed in the valleys. The levels of these lakes rise until they find an overflow. If the overflow channel is in unconsolidated material or in very soft rock, it may be so cut down as to permanently change the course of the drainage.

In the third condition, the ice at some point moves across the valley or basin of a river, whose general course is parallel to the ice margin. When this happens, the upstream part of the basin is ponded, and, if the ice occupying it rises higher than the lowest point on the basin's rim, the ponded water will escape at that point; but if the ice does not thus completely block the valley, the ponded water up stream will flow over the ice or between it and the wall of the valley. In the former case, if this new channel continues in use long enough, it may become the permanent course for the drainage of that part of the original valley.

In the glaciated area, many drainage changes have been attributed to ice. Later investigation of some of these reversals appears to throw doubt on the former explanation. Evidence has been found, showing that the reversals had been accomplished before the glacial period. In another section, I consider some of these cases.

CAUSE OF GLACIAL PERIOD

Many explanations have been offered for the extensive glaciation of certain parts of the continents. Most theorists have proceeded from observations made in our temperate regions. Above the snow line in mountains, snow accumulates in accordance with the precipitation. With an increase of snowfall through several succeeding years, the snow line is lowered. Under an equal period of diminished precipitation, the altitude of the snow line rises. It is urged, therefore, that a prevalence through centuries of the former conditions would extend ice fields down the slopes of the mountains and into the adjacent plains.

Former higher altitude of continent. Consequently, the explanation most universally offered for a glacial period rests upon a high altitude of the continent. Those who advocate this urge that, preceding the Pleistocene period, northern North America must have had a much greater altitude than at present. They do not urge that this altitude was maintained throughout the period, but that it existed long enough to make extensive snow fields, from which ice moved over adjacent regions.

Altitude alone cannot make an ice sheet. In many of our continents to-day there are extensive areas of great altitude, but no large snowfields. More essential than altitude, in inducing glaciation, is precipitation. A region may be but slightly above sea level; if its winters are long enough and a heavy snowfall occurs, which the succeeding summers do not waste, eventually ice will be formed. Therefore, the relation that an area bears to winds and the consequent precipitation, and the relative length of its summers and winters, are important elements in the probability of glaciation.

Change in position of the earth's poles. It was once thought that the earth's interior was in a hot, liquid, condition, and that man and other organisms lived on the cooled, solidified crust. On these premises, it was urged that tidal influence might shift the polar areas into lower latitudes, the "crust" slipping on the molten or plastic interior, thus changing the geographical location of the the glaciated regions, and inducing the development of ice fields in regions which were shifted to the polar positions. This liquid interior and thin crust theory is no longer accepted; physicists have taught us its impossibility. If the premises were correct, and if glaciation were always developed at the poles, the explanation would certainly account for temperate zone, and even tropical ice fields.

Change in eccentricity of the earth's orbit. This theory was advanced by James Croll.[3] That the eccentricity of the earth's orbit is not constant, is an accepted fact. The present difference in the earth's distance from the sun between the perihelion and aphelion positions is about three million miles. The direct heat received from the sun varies inversely with the square of the distance. When the eccentricity is at its maximum, the difference between the perihelion and aphelion positions is about 14,000,000 miles; and the heat received at these two positions varies as 19 to 26. At the present time, the winter of the northern hemisphere occurs when the earth is nearer the sun; in 10,500 years the earth will be nearer the sun in our early summer. If winter in the northern hemisphere should come at the aphelion position, we would be about eight and a half million miles farther from the sun than now, and in consequence would receive one-fifth less heat in winter and one-fifth more in summer. If aphelion winter of the northern hemisphere should coincide with the maximum eccentricity of the earth's orbit, the winter would be 36 days longer than the summer.

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[3] *Climate and Time in their Geological Relations* (1890), pp. 312–328.

The above are some of the important facts that led Mr. Croll to associate our glacial period with astronomical conditions. This explanation is ample to account for low temperatures, that would insure precipitation, if any fell, in the form of snow. If we knew approximately the time that has elapsed since the Pleistocene ice sheet commenced to develop, we could tell whether winter in the northern hemisphere happened at the time of the earth's maximum eccentricity of orbit. But there does not appear to be an agreement among students of astronomy, in reference to the variation of the earth's eccentricity during the past, We do not yet possess data of the behavior of other planets of our system, extending over enough time to make it certain that variation in their position might not vitiate our present conclusions of the past changes in the earth's eccentricity of orbit. The other planets probably account for the earth's orbit not being circular, and, as their alignment changes, the earth's orbit must also change. In any event, Croll's explanation makes a strong appeal to some students of the subject.

Variation in the content of the earth's atmosphere. Our present atmosphere is well understood. We know the gases it contains and the proportion in which they exist. A study of the earth's strata of the past geologic periods, and the life which existed when these rocks were being deposited, points to very appreciable variations in climate. During the Miocene period, animals of tropical waters lived in high latitudes. During the Pennsylvanian period, it is customary to hypothecate a mild and moist climate; this conclusion arises from a study of the flora that existed. It is quite universally agreed that climatic changes have taken place in the earth's past.

Practically the only source of the surface heat of the earth, worth considering, is the sun, and according to present ideas of earth origin, this has always been the great source of heat. Sunlight warms the surfaces exposed to it. How long the heat remains in these surfaces depends upon their capacity for radiating heat. Some rocks hold heat longer than others; water holds the heat longer than any rock. The sun's rays, coming through the atmosphere, do not appreciably warm the atmosphere, but heat radiated from the warm surfaces of the earth does raise the temperature of the atmosphere. If the heat thus radiated were kept near the earth, or if the atmosphere were kept quite constantly warm, climatic conditions would alter.

Some gases act as blankets and keep radiated heat from passing quickly through them. Water vapor and carbon-dioxide belong to this class. It is supposed, therefore, that if the present content of carbon-dioxide and water vapor in the atmosphere were increased, the mean annual temperature of the earth woud be raised accordingly. One estimate says that two or three times the present content of carbon dioxide would raise the average temperature 8 or 9 degrees; and that if the present content of carbon-dioxide were reduced one-half to two-thirds it would lower the average temperature 4 or 5 degrees. The former condition of higher temperature is thought to represent the climate of the Miocene period; the latter condition, that of the Pleistocene. Studies of the rocks have led students to conclude that there has been a variation in the amount of carbon-dioxide in the earth's envelope during the past, and it is further concluded that the same causes will bring about in the earth's future a repetition of this variation. To discuss this latter point completely, would involve much detail that would hardly be in place in these chapters. Those interested are referred to the literature where the matter is fully considered.[4]

This theory of change in the earth's atmosphere makes a stronger appeal to the students of the present day than do any of the other theories advanced to account for the glacial period.

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[4] Chamberlin and Salisbury, *Geology*, vol. iii, (1906), pp. 432–445.

COMPLEXITY OF THE PLEISTOCENE GLACIAL PERIOD

In this discussion, so far, I have spoken of the glacial period as a unit, as a simple affair. For a long time it was so considered; but more careful study of glacial deposits has shown that all drift is not of the same age. The age of glacial deposits is determined somewhat by the extent of weathering which they show. In a given time, chemical agents will make certain changes in drift of certain content. Multiples of that time unit would bring about more marked changes in the same drift. Rainfall and resulting stream courses gradually roughen all surfaces. If we compare two drift plains, one of which is thoroughly creased by stream courses and the other but slightly altered, the rainfall of the two areas being the same, we conclude that the former has been subject longer to sub-aërial weathering. These two distinctions are the most obvious of the many that have led students to differentiate glacial deposits on the basis of age.[5]

Pleistocene stages. The drift in parts of northern North America represents at least four and possibly five distinct ice advances. It is thought that between each advance the glacier may not have disappeared completely; it probably receded towards the dispersion centers, and then readvanced. But the time interval between a recessional and the next forward movement was sufficient for some progress in the weathering of the drift last deposited, for the development of stream courses over some of the drift area, and for the reëstablishment of flora and fauna. As a given ice sheet receded, it is probable that plant life followed its margin closely. The types of plants that kept nearest the ice were necessarily arctic and subarctic; other types came into the same zone as the ice retreated further. When the glacier advanced again over that territory, part of this vegetation was buried and later drift was deposited on top of it, while much suffered degradation along with other materials. Decayed plant remains, mingling with disintegrated rock, develops humus or the soil. To-day in some localities we find two till sheets separated by a soil zone, frequently containing logs and other vegetation. Remains of animals are also sometimes found in connection with the succeeding drift sheet; thus we infer that animals had reoccupied the area after the former ice had gone.

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[5] Leverett, *American Journal of Science,* vol. xxvii, (1909), "Weathering and Erosion as Time Agents," pp. 349–368.

Each extension of ice did not attain the identical marginal limits of the preceding sheet. For example, the glacier of the last epoch, the Wisconsin, throughout part of the glaciated area, extended beyond the limits of any preceding ice sheet. This, however, was not the universal condition. The imbricated relationship exists at sufficiently scattered points to indicate very satisfactorily the conclusions about the succession of the drift sheets.

While we more commonly assert that the early sheets of drift are more weathered than are the later, at the same time, it must be borne in mind that the better understood evidences of weathering may be more obvious in the deposits of later ice sheets. Oxidation, particularly of deposits with a ferruginous content, gives rise to the rusty and yellow appearances usually asociated with weathering. The lower parts of an earlier drift sheet, which had not been reached by weathering agents before the area was spread over by a later ice sheet and permanently buried, may show much less indications of weathering than does the surface part of the most recent drift sheet. Furthermore, the early over-ridden deposits would be made compact, and percolating ground water might more closely cement its parts, thus indurating it. Again, this early drift, when over-ridden by later ice, would suffer strains and stresses, and joints and faults would be induced thereby.

Where a post-glacial river has cut a channel through succeeding drift sheets, or where the wave work of lakes has developed a cliff exposing different drift sheets, we have the best opportunity of studying their appearance. When a later sheet failed to reach the margin of an earlier sheet, we can best observe the different extent of stream development on their surfaces.

OTHER GLACIAL PERIODS

It is not many years since geologists gave general credence to the scattered reports of workers in South Africa, India and Australia, concerning the existence of glacial conglomerates belonging to the Permian and Cambrian periods. Many had supposed that the Pleistocene glacial epoch was itself convincing proof of the earlier theory of molten interior and the cooling crust of the earth. The extensive continental glaciers of the Quaternary fitted well into the early idea of earth-origin.

To day it is generally accepted that our rock horizons show four distinct glacial periods. The earliest, and the only one which is not as yet fortified by data convincing to all students, is connected with the Proterozoic period. The next belongs to the Cambrian, then the Permian, and finally the Pleistocene, the most recent period.

Evidences of earlier glacial periods. Metamorphosed glacial products become clastic rocks. Glacial gravels and sands, when indurated, can not always be distinguished from similar sediments of non-glacial origin; but glacial conglomerates usually have distinctive features. The heterogeneity of this conglomerate usually distinguishes it from any other clastic rock that is catalogued as a conglomerate. Whereas it is possible to find in rivers conglomerate stones that have been striated while they were held fast in floating blocks of ice and came in contact with other rock, yet such striated bowlders are very rare. Consequently, a conglomerate rock which contains many polished and scratched bowlders is of glacial origin. Furthermore, the matrix of glacial conglomerate, containing, as it does, a large percentage of bowlder clay, has distinctive features, which are obvious when examined in thin sections under a microscope. While a widespread conglomerate, with numerous striated bowlders in a matrix of glacial clay, is good proof of a glacial period, at the same time, to remove the matter entirely from doubt, such a conglomerate, locally at least, should overlie scored, grooved, or striated rock surfaces; glaciation is the only agency that is known to thus alter rock surface. These two lines of evidence make the definition of a remote glacial period conclusive.

Proterozoic glaciation. Of these earlier glacial invasions, the evidences supporting this one has only recently been published. In Canada, in the vicinity of Sudbury, Professor Coleman of Toronto, over two years ago, studied a conglomerate rock, which he interprets as glacial in origin. His later reports array proof which has been accepted by many other geologists. Field work has not yet shown how extensive this conglomerate is. It should be remembered that, according to current ideas, our continent was very small during the Proterozoic period; also, that the rocks then in existence have suffered much from weathering and erosion during later periods. It is possible, therefore, that an extensive glacial formation of this early period may have been quite largely removed during later time.

A more interesting fact, however, connected with the Huronian ice age, is the bearing it has on formerly accepted ideas of conditions that prevailed immediately preceding the Proterozoic period. The rocks of this early period are sometimes thought of as cooled magmas or congealed liquid material of the parent earth; and the absence of fossils in these early rocks has been explained by saying that the surface of the earth was then so hot that life could not exist thereon. If glacial conditions existed in a particular part of the Proterozoic continent, it is quite conclusive evidence that there, at least, the surface was not warm.

Geologists of Norway also report conglomerate, suggesting glacial origin, belonging to rock horizons that appear to correlate with the Huronian of North America. If their correlation is correct, this early period witnessed glaciation in two distant parts of our sphere.

This early glacial period has a significant bearing on our ideas of the origin of the earth. Such refrigeration could hardly be possible under the nebular hypothesis. It is, however, entirely possible under the planetesimal theory of earth-origin.

The Cambrian glaciation. In connection with studies carried on in China, under a Carnegie grant, by Bailey Willis and others, a conglomerate horizon of glacial origin was located in the upper Yangtze valley. This horizon contains beautifully striated bowlders, as well as other conclusive evidences of glacial origin. Its location in the geologic scale is also made definite by the fact that it immediately overlies a formation whose fauna is well known. Glacial conglomerate of the same age has been identified in south Australia.

The Permian glaciation. In India, Africa, and Australia the existence of glacial conglomerates belonging to this period has been established. No other pre-Pleistocene glaciation is more thoroughly understood. In south Africa, these conglomerates were pointed out a long time ago, but students were very slow in accepting the interpretation. The time correlation of beds in such distant parts is made definite by relationship to other horizons bearing well known fossils. In south Africa, the glaciated surfaces underlying these conglomerates are as beautifully preserved as surfaces similarly altered during the recent ice age. Weathering and erosion have locally removed the conglomerate, revealing the scored and grooved rock surfaces beneath.

Detailed studies in Australia show that the Permian glacial period there was complex, in that the ice did not make an advance and then disappear, but there were several readvances, spaced by warmer conditions, producing in succession till and shale, separated by other deposits. Coal beds are found in some of these interglacial periods. Furthermore, the flora of the horizons itself reflects glacial climatic conditions.

Much speculation is possible on the basis of these three widely separated regions containing glacial conglomerates of the same age. Did all three belong to an extensive land area occupying the position of the Indian ocean? Whatever may have been the association or disconnection of these three distant tracts, it is certain that climatic conditions very unlike the present then existed. The Indian glaciated area lies near and north of the equator; the Australian region, not very far south; while the African is a little farther away. Possibly in the Permián ice sheets there is a suggestion as to the cause of glacial periods. Unless we can prove marked shifting in the location of the poles, it must be accepted that glacial conditions can exist in the tropical belt.

In South America, glacial conglomerate belonging to the Permian period has been studied. The matter has recently been under investigation, but the reports of the work are not yet available.

Conclusions. With four well established times of glaciation scattered through the geologic scale, it would appear that glaciation is a normal, not an abnormal feature in earth-history. When men labored under the idea that there had been only the one glaciation, it was interpreted as an abnormal condition. Whether these four periods are rhythmically spaced, we do not know. Man has not yet learned how to measure geologic periods. We merely feel that the Permian is very much nearer the present than is the Cambrian; but this gives us no definite conception.

Professor Chamberlin, who has most convincingly explained the carbon-dioxide and water-vapor cause of glaciation, has shown how the past glaciations may be a normal feature of earth-history. Briefly the explanation is this: With continued base-leveling of land areas, the epicontinental parts of the seas were broadened and on the lowered lands plant growth became more luxuriant. As the base-leveling proceeded, the limestones and other rock horizons were disintegrated; the amount of carbon dioxide in the ocean, as well as in the atmosphere, was increased. Extensive lime deposits were again made and luxuriant plant life spread over the base-leveled continents. With the formation of limestone, the quantity of carbonates was much reduced in the oceans; and the unusual consumption of carbon dioxide by vegetation tended to deplete the atmospheric content of this gas. With a reduction also of the water-vapor of the atmosphere, heat was quickly radiated from the lands. The mean annual temperature of the earth was much reduced; in these parts where ocean currents, winds, and land areas maintained the correct relationship, precipitation in the form of snow followed. Succeeding the base-leveling, deep-seated crustal movements, consequent probably on the over-loading of the ocean basins and lightening of the continents, tended to uplift the land and possibly also to elevate some submerged tracts, either forming new lands, or at least changing the course of ocean currents. This matter of elevation of land areas is a contributory factor, probably, in deciding the form of precipitation; furthermore, the increased elevation of the lands facilitated the carbonation of rocks, thus tending to further deplete the atmosphere's carbon dioxide. Only in the parts of continents where the prevailing winds and sufficient altitude, or the correct latitude, combined to induce snow, did ice caps develop. Snow-fields might result, therefore, either in the tropical or in higher latitudes.

It is well understood that the direction of ocean currents is partly controlled by the location of land areas. If, for example, North and South America were not connected, and the northern part of the equatorial drift current were to continue directly west, instead of being diverted northward in the "Gulf Stream," as it now is, great changes in the climate of Europe would result; there might be greater snowfall in western Europe. On the basis, then, of a cyclic variation in the atmosphere's content of carbon dioxide, following base-leveling periods, and their possible coincidence with such changes in the outlines of continents as might alter the courses of some ocean currents, we have, at least, a working hypothesis for the several glaciations and their geographical distribution during geologic time.

THE GLACIAL DEPOSITS OF OHIO

Local topography is always a factor both in the distribution and in the nature of glacial deposits. The gross relief features of a region determine the outline of the ice during its precessional and recessional movements. Minor relief features and the quantity of waste material present have a bearing on the amount of drift which the moving ice may locally acquire. Since moraines and other glacial deposits represent the débris within the ice, it follows that conditions tending to give the ice a load are factors to be considered in studying the drift of an area.

Glacial lobes in Ohio. Before the glacier had moved into Ohio, the lowland, which is now the basin of the present Lake Erie, induced in its front a pronounced lobation. This basin gave the ice sheet its general outline through Ohio and part of Indiana. Topographic features in Ohio determined the grosser marginal details on the south side of that lobe.

Commencing in the northeast part of the state, we will consider the relief features that determined the shape of the glacier margin. Preglacially, the Grand River valley was mature. For this reason, its course was filled by an extension of ice reaching ahead of the main sheet. Along the margin of the Grand River lobe, moraines accumulated. It is by a study of the moraines that we are able to-day to outline the form of these lobes. During the extreme reach of the glacier, the Grand River depression ceased to impress its topography on the shape of the ice front, as the sheet had extended south beyond the headwaters of the valley. Again, during the recessional stages, the lobe pattern of this valley became evident.

When the ice sheet was near its southern limits, south of or in the vicinity of Canton, its front described an arc, the western limit of which stood near Mansfield. This minor lobate form appears to be due rather to higher bounding altitudes than to a marked valley. If a valley lowland existed here, its axis should be along a line from Millersburg to Wooster. The drift here is heavy, and some work has already been done, showing that former drainage lines have been buried.

The Scioto River valley induced a beautiful lobation in the ice front, till it had retreated north of Marion. Between Marion and Chillicothe are many rudely concentric lobate moraines, indicating the successive positions of the glacier in its recessional movement through the Scioto valley.

The Miami River valley also occasioned a lobate outline in the ice sheet, most pronounced at its maximum extension. This relief feature appears to have imposed itself upon the ice only while its margin was south of Troy. The western part of the Miami lobe included territory in Indiana. The highland in Logan county accounts for the irregular course of the Erie lobe moraines in that vicinity, as if they were festooned at a point north of Bellefontaine.

After the ice sheet, during its recessional stages, had withdrawn northward from the above valleys, its outline was determined by the basin of Lake Erie. Therefore, in the northern part of the state the moraines are concentric, bordering this basin; whereas, south of this area they are arranged in a series of loops, occupying the valleys just described. Between these minor basins, the ice formed a reëntrant angle. The position of this reëntrant angle is marked by the coalescence of the drift of the lobate moraines; consequently, we have concentrated drift along a more nearly north-south line wherever the lobes blended. Between the Miami and Scioto lobes, this blending of frontal moraines accounts for the thickened drift northward from Springfield to the vicinity of Kenton. On the eastern side of the Scioto valley, the drift is heavy from Lancaster to Mansfield; this thickened drift marks the margin of the Scioto ice lobe, east of which there was no corresponding lobe until we reach the meridian of Millersburg. The depression, whose axis appears to be determined by the line connecting Millersburg and Wooster, blends into that of the Grand River lobe along the meridian of Canton, between which place and Akron the drift is very thick.

Ice lobe margins. Leverett's map of the drift in Ohio gives the distal positions of the glacier, as indicated by the more conspicuous retreatal moraines.[6] To determine accurately the minor details of the ice front will require more study. Neither our Federal nor State Surveys have been able to take up this work. It will necessarily require a great deal of time and expense. In some parts of our state, particularly in Licking County, on the east side of the Scioto lobe, closer study has been given the outline of the ice at its extreme position. It has been found that the glacier margin varied in shape with the topography. Wherever valleys existed, minor tongues extended beyond the main body of the ice; the relief in eastern Licking County is irregular, consequently there were several ice dependencies. Consulting a map[7] of the ice front in this county, one may note that in the vicinity of Wilkins' Run a minor dependency extended eastward over a mile; that along the parallel of Newark, a dependency reached into Muskingum County, a distance of some six or seven miles beyond the main glacier. Eastward from Buckeye Lake, another dependency extended through Jonathan Creek; this latter ice tongue appears itself to have been irregular, sending out secondary branches into confluent valleys.

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[6] *Monograph XLI,* U. S. Geol. Surv. (1902), plate ii.

Many interesting problems are connected with the more accurate mapping of the ice front. It is hoped that students in several parts of the state may take up this work, and that eventually the glacial boundary line in Ohio may more accurately represent real conditions.

ICE FRONT LAKES

The divide between the Ohio River and Lake Erie basin drainage is to-day very irregular. The rivers which flow into Lake Erie send their waters to the Atlantic by way of the St. Lawrence. If a barrier should be raised across the St. Lawrence at the eastern end of Lake Ontario, this lake would enlarge; if the barrier were sufficiently high, and a similar obstruction were placed across the Mohawk valley near Rome, N. Y., Lake Ontario would blend eventually with Lake Erie. If such a barrier stood only across Niagara River, the waters of Lake Erie would continue to deepen till some other outlet were discovered.

During its recessional stage, as soon as the ice sheet had withdrawn northward from the divides between the tributaries of the Ohio River and Lake Erie, water began to pond along its margin. This happened at many disconnected places. Each local lake thus formed increased in size till its waters flowed southward towards the Ohio, and, with further recession of the ice sheet, these small local lakes grew larger, and blended. At first they were distinct, because local divides existed between them, divides that had a direction transverse to the front of the ice. The ice withdrawing down the slope of these divides, all of which inclined to the north, allowed the local bodies of water to coalesce. In time a lake paralleled the front of the ice, and had an outlet westward through Fort Wayne, Indiana. The name, "Maumee," has been given this ice front lake.

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[7] F. Carney, *Journal of Geology*, vol. xv, (1907), pp. 488–495, fig. 2.

Lake Maumee. Under the direction of the Ohio Geological Survey, during the years 1869 to 71, G. K. Gilbert, in connection with other investigations in northwestern Ohio, did the first work in mapping this lake, noting its beaches and other shore phenomena. He mapped the morianic ridges also, thus determining the outline of the Erie ice lobe, in front of which Lake Maumee stood.

The wasting of the glacier itself, with the accession of the drainage from the basin south, was so great that water ponded rapidly in front of the ice sheet. The general trend of the shore of this lake in Ohio was east-west; in Michigan, north-south; in form it was saddle-shaped, resting against the Erie ice-lobe. After the Fort Wayne outlet, now 735 feet above tide, was uncovered, Lake Maumee continued its overflow in that direction till the ice had retreated far enough to disclose, somewhere north or east, a place of lower altitude; then a new overflow channel would be established. This, however, did not occur till the ice sheet had withdrawn northward in Michigan to the vicinity of Imlay, in Lapeer County. This new overflow channel was revealed near the reëntrant angle between the Erie and Saginaw bay lobes; its altitude is only fifteen to twenty feet lower than the Fort Wayne channel.

I have already explained (p. 195) how minor advances sometimes characterize a general recessional movement of the ice. In consequence of such oscillations, it is thought that the Fort Wayne outlet was temporarily used for short periods even after the Imlay channel had been uncovered. The overflow channels of ice-front lakes, particularly when near the ice itself, as was the case in the reëntrant between the Erie and Saginaw lobes, carried great quantities of water, sometimes laden with cutting tools. For this reason the channels themselves were degraded, and, as they were cut down, the general level of the lake declined. At first, it is probable that the altitude of the Imlay and Fort Wayne channels did not differ much. If the Imlay outlet were in use a considerable period of time, this lower stage of Lake Maumee should be marked by beaches and other shore phenomena corresponding to, but lower than, the original beach.

With a further retreat of the ice a new outlet north of Imlay was revealed, the Ubly channel; its altitude is about thirty feet lower than the former. In consequence, the level of Lake Maumee fell this amount.

The Whittlesey stage. This lower lake is called Whittlesey, after one of the early geologists of Ohio, Colonel Whittlesey, who was connected with our first Survey, organized in 1836. During the Whittlesey stage, a continuous sheet of water extended across northern Ohio. This lake was at least 160 feet deeper than the present Lake Erie. It drained across Michigan into glacial Lake Chicago, the name used for the water in front of the Chicago ice lobe. Lake Chicago overflowed through the course followed now by the Chicago sewage canal, into the Illinois River, thence to the Gulf. The Erie basin ice lobe, during the Whittlesey stage, blended eastward into the margin of the glacier extending across western New York. Therefore, Lake Whittlesey reached from the state of Michigan, on the west, to Central New York, on the east. Its margin across Ohio is marked by a splendidly developed shoreline, which I discuss in a later section.

It is evident that Lake Whittlesey endured till the ice had withdrawn from some divide in New York state lower than its overflow in Michigan. The ultimate control of the western outlet, then, was an altitude that might be revealed along the southern slope of the Mohawk lowland. During the entire existence of this lake stage, the ice sheet filled the Mohawk area, and abutted the Catskill region south. It is very likely that before the close of the Whittlesey stage, its waters flowed both to the east and west. This condition would naturally follow when the ice sheet should withdraw sufficiently down the southern wall of the Mohawk valley to disclose a level not very much higher than the Ubly outlet. With a slight difference in the level of two channels, a continuous west wind might cause an eastern overflow, temporarily at least. Thus, for some time, Lake Whittlesey may have overflowed into the Atlantic by the two routes. When, however, the ice had appreciably retreated in the Mohawk lowland, the level of Lake Whittlesey was bound to fall correspondingly, and a new outlet be permanently established.

Lake Warren. This next lake level, which overflowed through the Mohawk valley, is thus named. Its outline may be traced entirely across Ohio. Lake Warren included the ponded waters in the Saginaw Bay valley, waters in the Detroit region, waters extending across the present basin of Lake Erie and continuously through Cental New York. Warren thus had many times the area of our Lake Erie. How long it existed we have no way of telling. Judging from the pronounced beaches and other shore phenomena which now mark its level in Ohio, it must have endured a long period. Its existence was terminated when the ice retreated sufficiently to disclose a still lower outlet.

THE ORIGIN OF LAKE ERIE

Much has been written on the origin of our Great Lakes. In genesis they are associated; therefore, it is difficult to discuss one without going into the origin of all of them.

Lakes in general. It is well to remember that lakes are always short-lived. Frequently they are but broad portions of rivers; as the river lowers its bed, these broader sections are drained to normal channels. Other lakes occupy basins due to various causes, but in time, the outlets of these basins will be cut down and the lakes be drained; the only insurance against such a termination of a lake is found in basins below sea level, in a humid climate; in this case, with sufficient rainfall, the lake surface will rise till it reaches an outlet; the erosion of this outlet, and the deposits of streams in the basin will eventally bring the lake to an end. Along ocean borders bodies of water are sometimes isolated, forming in a short time brackish lakes and eventually bodies of freshwater; such lakes are also temporary, because vegetation, generally with the aid of sediment from streams, fills them. Of the several details that make up the features of our land surfaces, few, if any, are less enduring than lakes.

It is an obvious fact that those parts of the continents which have many inland bodies of water have been recently glaciated. South of the ice margin in North America and in Europe, very few lakes exist. Our knowledge of the conditions that surround the lakes of Africa is not sufficiently complete to assert their origin; it has been suggested that part of them, at least, occupy rift valleys, that is, depressions due to the subsidence of a long block of the crust between adjacent portions that remained stationary; the valley of the Jordan and Dead Sea is of this origin. Since, therefore, most of our lakes occur within the glaciated portions of the continent, and since Pleistocene glaciation is so recent, it is easy to accept the conclusion that lakes are geologically temporary.

The St. Lawrence drainage basin in preglacial times. Our Great Lakes are virtually but parts of the St. Lawrence River. The St. Lawrence River then is very peculiar. Normally, a river and its tributaries form a symmetrical outline, and among these tributaries there is an orderly arrangement. It is commonly thought that the Great Lakes occupy preglacial stream courses. The St. Lawrence and the lakes within its basin do not conform to a normal drainage pattern. Lakes Superior and Michigan unite in a manner that is not out of harmony with the confluence of stream tributaries; but, when considered in connection with Georgian Bay and Lake Huron, they together present an unusual alignment for drainage courses. It is very evident that the St. Lawrence drainage is abnormal.

Whatever may have been the pre-glacial topography of this area, the present Great Lakes are not parts of a former continuous river system. Before the ice sheet spread over the region, valleys must have existed. The perplexing question is as to the direction of flow of these valleys. Many conjectures have been offered on this point. Most of these suggestions are based upon the established presence of buried channels, contiguous to many of these lake basins. It is thought that if a buried channel, entering Lake Erie, shows rock removed to a depth of 470 feet below the lake level,[8] some stream to which the channel was tributary, must have occupied its basin preglacially; and if this tributary has such a deep channel, the major must have been still deeper. About the margins of some of the other lake basins are found buried channels, the rock beds of which are even below sea level. Along the continental shelf, soundings have revealed canyon-like depressions, continuous with rivers now entering the Atlantic; thus we speak of the drowned canyons of the Hudson and St. Lawrence rivers. The submerged courses of these streams over the continental platform, and the existence of deep buried valleys about the Great Lakes of to-day, have led to the suggestion that pregla-

[8] Warren Upham, *Bulletin Geological Society of America*, vol. viii, (1897), p. 8.

cially, this part of North America must have had a much higher altitude. Such an hypothesis would make it much easier to understand this relationship of deep channel-cutting. At the same time, to accept a genetic association between canyons across the continental shelf and those farther inland would require our altering the accepted idea of river and valley development. While, in its headwater area, a river may occupy deep gorges, contemporaneously, its down stream section is found in wider valleys, and eventually, before reaching the ocean, the river's course should regularly be very old and flat. If, then, the submerged canyons and buried channels represent stream-cutting due to an uplift, they cannot be contemporaneous in origin. Many students are of the opinion that along all our continents the buried channels need not imply former greater altitude of the land areas, but instead a tendency of the continents to creep seaward, thus carrying with them the drainage patterns existing.

Just what is the origin of the buried channels about the present Great Lakes is an unsettled question. Before any conclusion can be reached, it will be necessary to know more thoroughly the extent to which buried valleys and channels exist; and since such knowledge is established only through drillings, it will probably be a long time before this desired information is obtained.

On one point, there appears to be complete agreement among geologists: The present lake basins, preglacially, were depressions or valleys occupied by streams. When, however, these students reconstruct that preglacial drainage, many opinions at once arise. I will state, briefly, the more widely published reconstructed drainage plans of this area. Among the early suggestions it was stated that preglacially, part at least, of the area of the present Great Lakes .was drained eastward through the Mohawk lowland. This assumption appears to have been suggested by the buried valleys south of Lake Ontario. To lead waters from the buried gorges of the region south of Lake Ontario, that could have been associated genetically with the continental-shelf canyons, would require a deep valley through part of the Mohawk lowland. No such valley has been found; furthermore it appears to be well established that it never existed. In the vicinity of Rome, N. Y., across the meridian of which, this hypothecated valley or channel must have led, continuous rock exists. Bearing on this point, however, and somewhat in harmony with the original suggestion, are the recently discussed buried channels of the Hudson valley, channels brought to light in engineering projects connected with the water supply of New York City.[9]

It has also been thought that the preglacial drainage of the Great Lakes area reached the ocean as it does to-day. The configuration of the present St. Lawrence valley precludes any such hypothesis. Its originator so grants, but he explains that since the close of the Wisconsin glacial epoch, tilting of the land has locally lifted the floor of the St. Lawrence valley, and that now its altitude is much greater than formerly. That land tilting of this nature has taken place in postglacial times is already well established through a study of the deformed beaches of ice front lakes. If the reconstructed drainage of the Great Lakes basin reached the Atlantic through the St. Lawrence area, the amount of land deformation required would certainly be beyond any conception held by geologists. This plan of reconstructed drainage has very few advocates.

Others have shown how the Great Lakes, with the possible exception of Lake Ontario, occupied depressions which preglacially drained towards the Mississippi basin. This reconstructed drainage is most generally accepted. Some differences of opinion appear in details. One investigator hypothecates a former river that followed, in general, the basins of the present Michigan and Superior lakes; another stream having its axis through Saginaw bay, and with its tributaries draining most of what is now the Huron basin and Georgian Bay; while the Lake Erie basin was drained by another river, whose headwaters included part of the Lake Ontario region. These three rivers had courses to the southwest. No attempt has been made to work out any further details as to their southern courses. This same geologist hypothecates another southflowing stream from the eastern end of Lake Ontario's basin, reaching the Atlantic through the Susquehanna system.

Local warping. Deformative movements of the earth's crust have been known to so bow original horizontal rocks as to produce a basin in which drainage, accumulating from the adjacent slopes, would form a lake. Where such a movement has made a basin, a study of the rock attitude should reveal the fact. Apply-ing this theory to the Great Lakes, it is found that Superior occupies such a synclinal basin; but it is generally understood that the other Great Lakes do not occupy warped basins.

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[9] J. F. Kemp, *American Journal of Science*, vol. xxvi. (1908), pp. 301–323.

Glacial erosion. There are very few geologists to-day who do not believe in the potency of glaciers in eroding rock basins. Basins thus produced, however, are almost always over-deepened portions of preglacial valleys. Concentrated ice erosion, in a portion of such a valley, is the explanation offered for the stupendous deepening noted in a few localities. Examples of basins thus produced are Lago Maggiore and other lakes about the Alps area; many of the Lochs of Scotland; Lake Chelan and a few others in the Rocky Mountain region; and part of the Finger Lakes of New York state. It is noted that all of these are long narrow lakes quite unlike the Great Lakes. Nevertheless some geologists have advocated the same theory for the origin of part, at least, of the Great Lakes. Some years before ice erosion was invoked to account for deepened valleys, J. S. Newberry, then connected with the Ohio Geological Survey,[10] urged that the rock of the Erie basin was easily carved by ice and had been sufficiently basined to account for the lake. His suggestion was given very little credence at the time.

When we consider the shape of some of these lake basins, particularly Lake Erie, it does not require very much basining of the shales to produce them. The average depth of Lake Erie is only 70 feet and its greatest depth 204 feet. Cross sections of this basin show how shallow it is, relative to its area. It does not seem at all improbable that the Erie-ice-lobe sufficiently eroded the fissile shales beneath it to make this shallow basin.

The erosive work of the continental glacier was accomplished almost entirely by the lobes and dependencies along its margin. Back from the front, where the ice was deep, it is not likely that the subjacent rock was very effectively abraded; but at the front, where a lobe or tongue, shod with tools, continued for centuries to wear and grind the rock beneath, some effect was certainly produced. Furthermore, these marginal forms of the ice sheet received the concentrated motion of the great ice mass in the rear; if the ice is a small lobe or tongue fitting into a valley, the side walls and boundary divides of which tend to obstruct the movement of the glacier, the great field of ice in the rear uses the valley tongue as an outlet, and consequently lines of movement converge towards the axis of this tongue. Such a tongue, or dependency, becomes a strong erosive agent, provided it is carrying the proper tools. In a similar manner, but in a slighter degree, a lobe of ice receives the onward impulse of a greater area in its rear; but the lobe is larger and is not occupying so confined a basin, consequently the erosive work done is not comparable to that accomplished in narrower valleys. Through the work of an ice lobe, a shallow basin like that of Lake Erie may easily be produced; under the concentrated work of a valley tongue, the deep Lochs of Scotland and the grossly overdeepened Ticino valley of Italy are natural.

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[10] Vol. i, (1873), p. 49.

While ice erosion was a factor in developing the basin of Lake Erie, at the same time it is apparent that land tilting has had something to do with the present size of this lake. In its western end the lake is shallow; if the eastern end, at the mouth of the Niagara River, were depressed 10 feet, the lake counties of the state, west of Huron River, would have their areas increased. Land tilting in postglacial times has tended to drown the western end of this basin. There was one period, since the ice retreated, when the lake was only a small fraction of its present size; indeed, according to some investigators, the basin held no lake, only a river. The obvious effect of the postglacial tilting, in increasing the area of a lake in the Erie basin, in nowise detracts from the part taken by ice erosion in making the basin. To be assured that glacial erosion operated here we have only to recall the evidences of it on the islands about Sandusky; the limestone resisted the corrasion of ice more than did the neighboring shales.

To what extent glacial erosion has been a factor in the development of the basins of the other Great Lakes cannot be proved. The amount of erosion, if the glacier made their present depths, is varied. Lake Superior is the deepest, but ice erosion is invoked less in accounting for its basin than in the case of the other lakes. Lake Michigan occupies a rock basin; its maximum depth, 870 feet, at first thought, would indicate a great deal of erosion. When, however, we consider its length and the width of the basin, as it is brought out in a cross section, with the same horizontal and vertical scales, this depth does not appear so great. Lake Huron, having a maximum depth of 702 feet is also in a rock basin.

We have absolute proof that ice lobes occupied each of these basin areas for a long time. The concentric moraines about the basins give us the pattern of each lobe at several recessional stages. Knowing that heavy bands of drift in recessional moraines usually contain a high percentage of local material, we infer that these concentric moraines are witnesses of long continued ice-erosion of the basins. A similar arrangement of moraines south of Lake Erie shows that its basin was also subject to the same mechanical work.

The orientation of the Huron basin does not expose it so directly to the erosion of ice from the Labrador dispersion center, as is the case with either Michigan or Erie. The direction of striae, and the arrangement of moraines, afford the evidences on which it is concluded that this part of the Great Lakes' area was under the influence of the Labrador center during at least the Wisconsin epoch of the glacial period. Whether the Labrador center exercised the same control during all the preceding glacial epochs is not known. The direction of Huron's basin indicates possible erosion from the Keewatin center. There is no reason to infer that, during the earlier epochs of the Pleistocene, these two dispersion centers controlled the same regions southward that they did during the last epoch; but at present we have no evidence that suggests a different ice control for the earlier epochs. Possibly, in time, we may have sufficient knowledge of the kinds of rocks found in the drift, and their particular sources in the north, to demonstrate whether there was always identity in the ice movements of the several epochs from the two dispersion centers.

In the absence of a more convincing explanation, it is probable that students will continue to regard these lake basins as largely the product of glacial erosion. We cannot infer the amount of over-deepening by ice, as we have no measure of the depth of these valleys before the ice entered. The most reasonable way of approximating the amount of ice erosion in any particular one, say the Michigan basin, is to note its depression below a line which probably represents the gradient of the former valley. The lake basin is rock-bound at either end. Allowing something for the erosion at these termini, in case it is thought that one end has suffered more erosion than the other, the line connecting their levels will be parallel to the gradient of the preglacial stream. A line drawn along the lowest bed rock of the present basin, therefore, represents the limit of erosion in the plain determined by the two lines.

Several of the other factors briefly discussed doubtless had some part in producing the Great Lakes. The most inclusive theory of origin is that stated by Chamberlin: "The basins of the Great Lakes are regarded as due to the joint agencies of preglacial erosion, glacial corrasion, glacial accumulations, blocking up outlets, depression due to ice occupancy and general crust movements, together with possible unascertained agencies."[11]

OLD SHORE LINES IN OHIO

Three ancestral lakes of Erie formerly stretched across our state. Each of these left such evidences of its existence as the present lake is now engaged in producing. If you visit Lake Erie at any point, you will observe that the water is either cutting into the shore, which is either till or solid rock, or else it is piling up material which the waves have carried. In the former case the waves are undercutting a cliff; in the latter, constructing a beach. These earlier lakes must have done similar work; what they accomplished, either in cliff-cutting or in beach construction, depended upon their duration. Wherever the former lakes made cliffs in rock, the result was more enduring than if the cliffs had been cut in unconsolidated material. Wherever they built beaches of cobble and gravels, this material has held its shape longer than beaches constructed of clay and sand. The sharpness of development in the shore lines of former lakes is conditioned by the lapse of time since they were made. We would expect, therefore, in case these three shore lines represent lakes which lasted through equal time units, that the oldest one would now be the least distinct; it has suffered longest from weathering. On the supposition that there has not been an appreciable change of climate in this area during postglacial time, this method of determining the relative ages of old shore lines is fairly accurate.

Origin of shore lines. A lake occupying a basin either of rock or unconsolidated material, or a basin consisting of both, will alter its basin somewhat through solution. A body of water remaining absolutely static induces chemical alteration; limestone is thus corroded below the level of wave action. But the efficient weathering work of lakes is accomplished by waves which depend upon winds. Winds through friction of the atmosphere against the water's surface, roughen the surface into waves. The impact of the waves upon the shore, driving tools against it, cuts the shore. The effectiveness of wave work shows more readily on a steep shore. When the marginal part of the lake-basin has a gentle slope, wave work is slow in establishing a cliff; if the slope is very long, the waves may never form a cliff, but instead, will pile up material off shore, there constructing a beach. After such a beach becomes well developed, wave work may steepen its outer slope, or even cut it as a cliff.

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[11] *Proceedings American Association Advancement of Science,* vol. xxxii, (1883), p. 212.

At all places along the border of a lake the waves are either undercutting, or piling material up. At different times during the year, depending upon the strength of winds, both processes may be in operation at the same place.

The shape of a lake has much to do with the efficiency of wave work on its shores. The longer axis of Erie coincides approximately with the prevailing wind direction. As a result its shores have been subject to vigorous wave work, both constructive and destructive. In case the prevailing wind direction has been the same through postglacial times, and there is no reason to think otherwise, the ancestral lakes of Erie experienced similar effects. The vigorousness of wave work to-day may be observed at most any point along the lake. The lake cities have to make annual appropriations either for retaining walls to save their front, for lengthening piers, or for dredging to make it convenient for vessels to land.

The development of cliffs. Active wave work develops cliffs either in unconsolidated material or in rock. The slope of the cliff is determined by its material, being steepest in rock; but the process of cliff development is the same in either case. Waves impelled by the winds wear the cliff by impact alone; when the water carries stones, the cliff is cut more rapidly. At the point of attack, the cliff is undercut; when undercutting has proceeded far enough, the overhanging material drops off. As a usual thing, where cliff-cutting is in progress, the waves are strong enough to develop a current along the shore, which removes the blocks that have dropped into the water, as they are ground to bits by the waves, thus keeping the base exposed to fresh attack. At some places on the lake, cliff-cutting has proceeded very rapidly even during the short period that the shores have been inhabited. Farmers have lost fields, and cottagers have had their property destroyed.

Beaches. Vigorous waves striking the shore are thrown some distance above the level of the lake. These waves push ahead of them the cobble, gravel, sand, etc., along the shore. Under the impulse of heavy winds, the huge waves drive material far up on the shore. This material then is pushed beyond the reach of waves. In the course of time a ridge is thus constructed, called a beach ridge. It consists of fine and coarser products, depending sometimes on the location of nearby cliffs, which furnish the material, and sometimes on the strength of the waves. Beaches usually alternate with cliffs. Recalling the preglacial irregularity of topography, you understand how Lake Erie could not be bordered by either continuous cliff or beach; in some parts one prevails and in some parts the other, but in no case can you travel many miles without finding both forms.

Along-shore currents. Under a fairly constant wind, the waves necessarily meet the shore, which is irregular, at various angles. If a wave strikes the shore directly, the water, after the impulse, settles back along the same line. With the continuance of oblique waves, the water is given a general movement along the shore. This constitutes an along-shore current, which is efficient in transporting the products of wave work.

Under-tow. When winds, even for an hour, drive waves against the shore, the water is piled up; and since a shoreward movement is continuous on the surface, the only escape for the accumulated water is along the bottom outward. This movement is called an "under-tow." The velocity of the under-tow depends directly on the strength of the winds causing water to accumulate along the shore. The higher the water becomes, the faster it will move down along the slope in response to gravity. An under-tow current, like any other water current, is a transporting agent. But, because of its relatively low velocity, the undertow carries only small material. These smaller pieces of sand, etc., represent the finer products of comminution by waves. As the result of deposition by undertow currents, the shore slope is gradually lessened.

Bays. Young shore lines are seldom even; but the denuding agencies of water tend always to straighten shore irregularities. Ultimately the oceans, in case of no change of level of sea or land, will change the most irregular shore line conceivable into an even line. Lakes, being short-lived, probably never accomplish this so perfectly.

The indentations of lake shore lines are due to headlands which represent the higher altitudes of the original stream-carved surfaces. Wave and current-work undercut and transport the degraded material of these headlands. The along-shore movement of the water distributes the materials thus acquired. Such a current, reaching a bay, is retarded both by the wave movement and by the mass of water in the deeper part of the bay. The velocity of the current being checked, its load is rapidly dropped. From the angle of the bay this deposited material gradually extends into deeper water; such a deposit is called a "spit." As the spit grows, a shallow water condition is maintained forward in the line of its axis, and the transporting current is able to move farther, before the on-shore movement of the deeper water in the bay checks the current and causes its load to drop. The influence of wave movement, in the deeper parts of the bay, manifests itself sometimes in bending the spit inland, developing a "hook." Later the spit may continue to grow in its original direction, and the hook will then appear as an irregularity on the land slope of the spit. Frequently a spit is developed also from the opposite side of the bay. In time the two may grow together constituting a "bar." A bar, however, seldom appears before the bay has been appreciably shallowed. There is a constant current moving out from the bay, in case it receives a constant supply of land drainage. Such a current keeps at least a narrow passage clear between the termini of the spits.

Spits are not always associated with bays. Sometimes such an accumulation starts and grows outward from a headland or even from the beach.

Water isolated from the lake by the development of a spit or a bar becomes a marsh. Vegetation gradually fills it in and the tract is added to the land. Bays, when shut off from the lake, pass through the marsh stage, at last becoming land. The abundant vegetation of these marshy areas, sometimes forming peat swamps, accounts for the muck soil found so extensively in the northwest part of Ohio. During all three of the ice-front lake stages, the Maumee valley, which always had a very low slope towards the axis of the Lake Erie basin, contained a bay. The shallowness of the bay encouraged the growth of spits and bars, converting successive parts of it into a marsh. This history was repeated during the Maumee, Whittlesey and Warren stages. As a result there were developed in that part of Ohio hundreds of square miles of muck land, much of which had to be artificially drained by the early settlers. This land is very rich, and when brought under cultivation makes profitable farms. Smaller muck areas are found the whole length of the shore lines of these three lakes.

Other shore line structures. Along the lake front one sometimes sees a deposit of sand and gravel, growing directly out into the lake. This product of deposition, called "a cusp," is due to the interference of waves and currents, causing a deposition of the load in transit. As the cusp grows, the interference area is increased, and the deposit is extended more rapidly; but upon reaching deeper water it makes little progress. After attaining some size, bordering barriers may develop, and later be tied to the cusp. By this process, a lagoon is formed between the cusp and the barrier; it passes through the regular lagoon history, and thus increases the cusp's area. By a repetition of this process, as well as by extensions made similarly through the development of spits, the cusp attains large proportions, and is then called a "cuspate foreland."

Especially along shallow shores, the larger waves break a considerable distance from the coast. The wave "breaks" because its diameter or height is greater than the depth of the water. Along the line where "breakers" form, the action tends to pile up the material at the bottom. This process eventually develops a ridge on the bottom that in time shallows the water sufficiently to catch even the smaller waves. With the lapse of more time, the ridge appears above water as a line parallel to the coast proper. In reality it is a new beach, and is called a "barrier beach." When barrier beaches persist, they are usually connected with cusps or headlands in such a manner as to isolate the water between them and the original shore. This creates a marsh which passes through the various lagoon stages. The barrier beach then becomes a shore ridge.

Rivers flowing into a lake have their velocity checked by the static water, and as a result deposit their loads. The products of stream erosion, thus deposited near the mouth of the river, build a "delta." Since streams vary with the seasons, in their velocity and volume, their loads are sometimes carried farther out into the lake before being deposited. If the volume and velocity were constant the year round, the river would shortly clog its own mouth and build a dam. Even under normal river conditions, deltas eventually attain such size that they rise above the lake level, and the stream takes one or several courses across it. Towns situated at the mouths of lake rivers are forced to make annual appropriations for dredging the stream, so as to keep the harbor open. Delta deposits gather rapidly, even at the mouths of old streams. Lake currents shift delta material somewhat, but never to the extent of distributing it all. About the borders of deltas, these currents form spits and barriers, which become a further menace to navigation.

The shores of islands have the same history as any other shore lines. If the island, through cliff development, furnishes an ample supply of material, lake currents will deposit spits, oriented with the prevailing wind. Sometimes barrier beaches are constructed, not infrequently, through the development of a bar the island may become land-tied. About all islands, we find the same catalogue of shore phenomena as are associated with the shore lines proper.

When the prevailing beach material is sand, dunes develop. The wind carries the sand in front of it, and, if the shore line lies athwart the wind, the dunes travel inland. Extensive dune areas are found in the northern part of the state, many miles south of the shore of Lake Erie. The material of these dunes represents the wave work of the high level lakes; they are especially abundant south of Sandusky, a typical area existing in the vicinity of Bellevue.

Geographic influences. Shore lines have elicited a variety of responses in man's activities. Long before anyone appreciated their significance, or even the former existence of ice front lakes, man used the old beaches for highways, frequently calling them "ridge roads." A high percentage in the linear extension of the beaches of the three ice-front lakes now carry highways. Even some of the spits, built into former bays, are used for roadbeds. In some localities, the three beaches are quite parallel for considerable distances; here the farms run from beach to beach, or the interval between the beaches is divided between either shore. Where the beach ridges are a mile or less apart, the farms usually are narrow. Wherever sufficient muck land exists, and the area is within easy reach of a city, the farms are small; they are cultivated intensely, usually by market gardeners.

These ridges usually furnish the sand and gravel needed for structural purposes and for roadbeds. As concrete comes more generally into use, the economic advantage of the old shore lines will be even better appreciated. In several locations the material is adapted to the manufacture of sand brick; elsewhere I have seen the lake clays being used for tile, and for various other kinds of brick.

Quite a variety of soil is associated with these shore lines. The local rocks have had a great deal to do in determining the soil. In the region south of Sandusky, the denudation work of waves on the outcropping limestone has accumulated great areas of very clear silica, or sand. This silica existed in the limestone; the carbonates were entirely dissolved. In these areas peach orchards do well; melons and other vines appear also to thrive on the rolling sand hills.

The botanist has long been acquainted with the shifting facies of plant habitats, bordering shore lines. Even to-day one finds all the plant families within the limits of a bog habitat on the one hand, and a very dry sand dune on the other.

Post-glacial tilting. A shore line should be horizontal. If it is not horizontal, it has suffered tilting since it was made. Beaches of nearly all the ice-front lakes show deformation. This is not noted appreciably across northern Ohio, but the beaches of the same lakes when traced into Michigan or into New York do show tilting. The axis of movement was such that it is not so manifest in northern Ohio. It is possible, however, that a closer study of our shore lines may show that they are not horizontal. One appreciates why it is not an easy matter to tell exactly the water level of a shore line which has been subject to subaërial weathering for several thousand years; if it is a cliff cut in rock, it has suffered less change, and more accurate definition is possible. Up to date no one has gathered data that establish much information of the high-level lake beaches across Ohio. In New York state some of these ancient strands have been very appreciably tilted. In the first one hundred and twenty-five miles of direct distance east of the Ohio-Pennsylvania state line, the Whittlesey beach rises 150 feet.[12] The Warren beach rises 42 feet between the east border of Ohio and Westfield, N. Y., a distance of 50 to 55 miles.[13] In a distance of 60 miles between Rome and Adams Center, N. Y., the Iroquois beach rises 235 feet.[14] These old shore lines do not show the same change in tilt; this fact suggests that the differential movement was in progress, as the lakes succeeded one another.

Land tilting in the St. Lawrence drainage basin is still in progress. Men have been watching it closely over half a century. It has been estimated that if the movement continues for 500 years, the tilt will have become sufficient to cause the upper Great Lakes to flow into the Mississippi valley by the old Chicago glacial lake outlet. The course of this outlet is now followed by the Chicago sewerage canal. This seems like a bold statement, but a study of altitudes shows that the tilt need not be very great to cause Lakes Michigan, Huron and Superior to flow southward past Chicago. Should this diversion be brought about, there will be very little water left to make a Niagara river. The falls will then cease to be of much importance.

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[12] Leverett, *Monograph XLI*, U. S. Geol. Survey (1902), p. 756.

[13] *Ibid.*, p. 765.

[14] *Ibid.*, p. 774.

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8. The abandoned shorelines of the Vermilion quadrangle, Ohio. By Frank Carney ... 233

9. Thermo-electric couples. By A. W. Davison ... 245

10. The Mercer limestone and its associated rocks in the Newark-Zanesville region. By Clara Gould Mark ... 267

11. A study of the supposed hybrid of the Black and Shingle oaks. By Earl H. Foote ... 315

12. A case of pre-glacial stream diversion near St. Louisville, Ohio. By Howard Clark ... 339

GRANVILLE, OHIO, APRIL, 1911

THE ABANDONED SHORELINES OF THE VERMILION QUADRANGLE, OHIO[1]

FRANK CARNEY

The literature contains a few references specifically to the raised beaches of this sheet. One is by M. C. Read[2] who published a cross-section of some terraces near Berlin Heights; another is by E. E. Wright[3] whose map of the lake ridges in Lorain and Cuyahoga counties roughly locates some of the ridges east of the Vermilion River; and they have been studied in places by F. Leverett[4] who briefly describes them.

Compared with adjacent sheets, the Vermilion has an irregular surface. The position of the Berea sandstone accounts for this fact; this formation outcrops across the northern part of the quadrangle (fig. 1), and its escarpment has been made very irregular by ancient stream erosion; as a result, many outliers exist. The area contains one major stream, the Vermilion River, which during post-glacial times has easily made a new base-level for many of the illy defined pre-glacial valleys. Should the history of this river be worked out, it is probable that its channel will be found, in parts at least, to represent pre-Wisconsin stream work.

From the level of Lake Erie, 573 feet, the surface of the sheet rises rapidly to the south. Away from the axis of the Vermilion River, the 800-foot contour nowhere is more than six miles south of the lake. Because of this fact, the abandoned shore lines are close together; they are found usually within a limit of two miles. These raised beaches lie so close together here because the Berea formation is so very thick. At the South Amherst quarries, which are located one and a half miles southeast of Brownhelm, the Berea has a thickness of over 200 feet. I have no data as to the exact thickness of this formation at Berlin Heights, but from the base of the escarpment to the highest point nearby where Berea rock exists, there is an interval of about 150 feet. In addition to this stratigraphic influence in bringing these old shore lines within a narrow horizontal range, the rock structure has also been a very strong factor in both the texture and the outline of the Whittlesey and Maumee beaches.

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[1] Read by title before Section E of the American Association for Advancement of Science, Boston, Dec., 1909, with the permission of the State Geologist of Ohio. The author is responsible for the facts given.

[2] *Geological Survey of Ohio*, vol. iii, p. 289. 1878.

[3] *Ibid.*, vol. ii, map opposite p. 58. 1874.

[4] *Monograph*, xli, United States Geological Survey, pp. 732–733, 751. 1902.

THE MAUMEE SHORE LINE

West of the Vermilion quadrangle these beaches trend to the south, on account of a bay which occupied the depression followed by the Huron River. Southeast of Berlin Heights, it is evident that the Maumee, during its earliest period, had an altitude of 780–790 feet. This position did not last long, but the multiplicity of disconnected ridges, and the great number of dunes at slightly higher altitudes, are evidence of wave-produced sand. Disconnected ridges are found also west and north of Florence. It is possible that they represent the work of a small local body of water along the front of the ice previous to the Maumee stage.

About Berlin Heights the shore structures are very irregular, a condition due to the dissection of the Berea. The high rock hills, which suggested the name of "Berlin Heights" furnished the waves an inexhaustible supply of sand. During the early Maumee stage these hills were islands and from their sides spits were developed, especially to the south and west, and winds shifted the sand into dunes making accurate mapping of the original beaches quite impossible.

Extending northeast from the "corners" in Berlin Heights is an extensive deposit of coarse beach gravel from which, several years ago, railroad ballast was taken. I have not found it possible to distinguish the two Maumee levels here, because the area has been so mutilated in removing the gravel.

Eastward from the quarry, located in the northernmost of these Berea outliers, a complex arrangement of sand and gravel ridges extends to and beyond Ogontz. The highest of these, which crosses the roadway about one-half mile south of Ogontz, is strong; it clearly represents the upper Maumee level. The shore line here at first curved to the south in a bay which was eventually shut off by the growth of a spit. The first spit-development

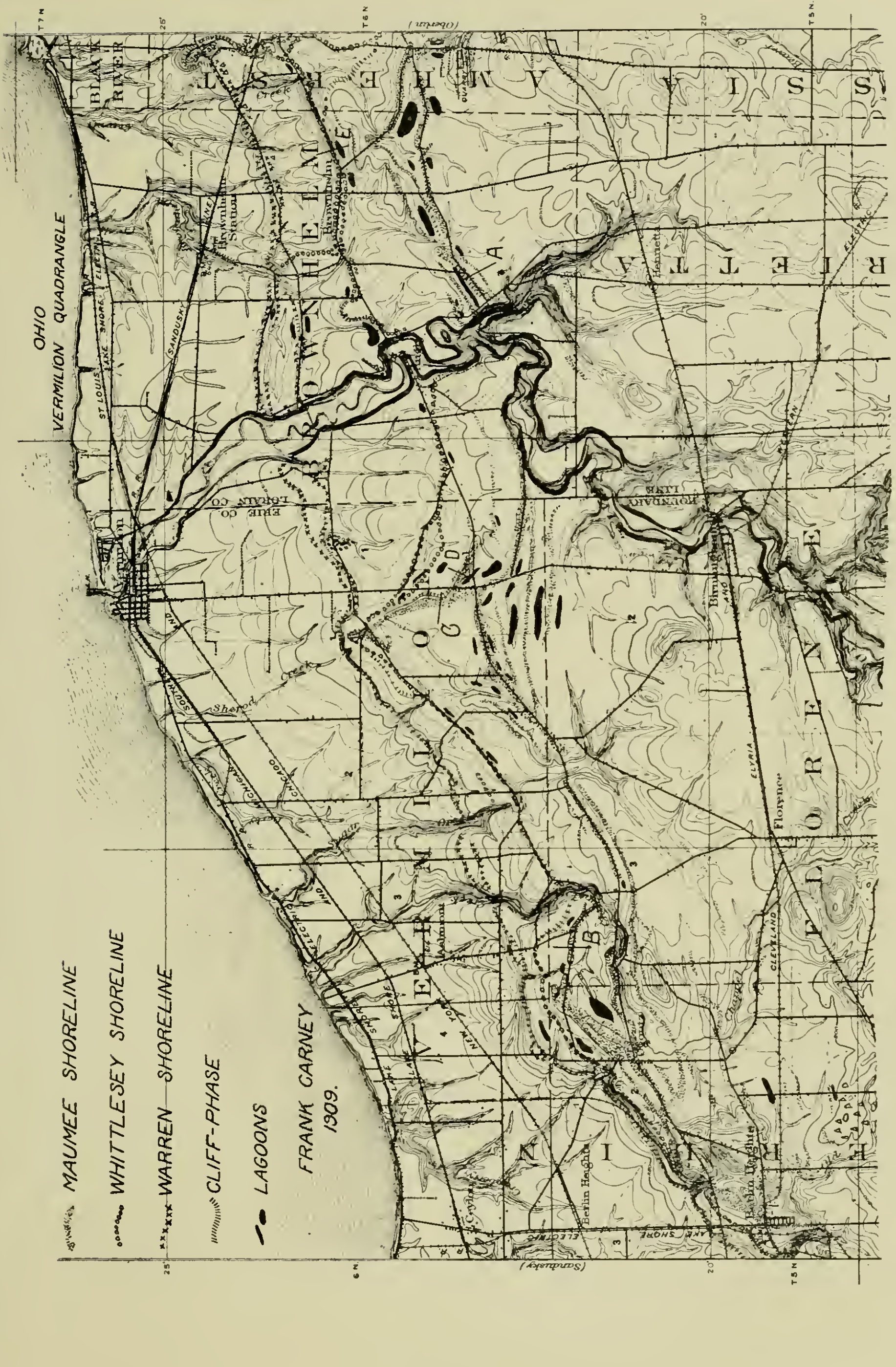
OHIO
VERMILION QUADRANGLE
MAUMEE SHORELINE
WHITTLESEY SHORELINE
WARREN SHORELINE
CLIFF-PHASE
LAGOONS
FRANK CARNEY
1909.
BLACK RIVER
Brownhelm Station
Brownhelm
Henrietta
ERIE CO.
LORAIN CO.
BOUNDARY LINE
Birmingham
Florence
Sherod Creek
Berlin Heights
(Oberlin)
(Sandusky)
LAKE SHORE ELECTRIC
NEW YORK CHICAGO AND ST. LOUIS
CLEVELAND ELYRIA

Fig. 1 Scale is Approximately $\frac{1}{126000}$. The Small Triangles Indicate Sand Dunes.

proceeded eastward over one-quarter of a mile; the second one, which eventually became the shore line, is followed by the highway from Berlin Heights to Ogontz. This beach eastward is quite parallel to the earliest ridge; Chappel Creek flows between the two. Just south of this area is another outlier of Berea sandstone which has an altitude of 830 feet; this afforded a good supply of beach material. North of this outlier the beach developed a cusp; eastward the shore line at first turned to the south; later, however, this irregularity was straightened, leaving the earlier ridge isolated. From this vicinity eastward for nearly two miles the Maumee beaches are parallel; locally they have been united by wind-drifted sand.

At a point about two miles west of the Vermilion River the shore line of the upper level again becomes very irregular. This condition is due probably to the two factors: one, abundance of beach material supplied by outcropping sandstone; the other, the slight bay in the depression now occupied by the Vermilion River, which the shore line tended to straighten. At first this bay was approximately two miles deep, extending south to the vicinity of Birmingham; but this stage did not last long because of the growth of spits from the western angle of the bay; enough gravel and sand, however, has been found in scattered segments to establish its early outline. The numerous lagoons, forming in parallel series, show the successive development of spits into bars before this Maumee shore line became stable. So far as can be inferred from a study of the ridges, it seems evident that the final position of the upper beach here was strong enough to account for the east-west direction of the Vermilion River for about a mile. I have mapped this ridge a little east of the angle where the river turns south, but have hesitated to carry it farther eastward because so much of the beach materials has been removed by the under-cutting of the stream. That there was abundant gravel and sand farther east of it, however, is shown at disconnected points, especially in the pre-historic earth works about one-quarter of a mile east of the highway that rises northward up out of the river valley.

On the east side of the Vermilion River the highway trending a little north of east follows the upper Maumee shore line. Throughout the whole of this distance the beach is very distinctly marked, and has been cut by recent drainage at only one point; for the first mile, there are two distinct ridges (fig. 2A). Near the eastern margin of the sheet the Maumee beach turns directly south, bordering a bay in the Beaver Creek depression of the Oberlin sheet.[5] The extensive quarrying operations at South Amherst have made definite mapping of the beach in this locality impossible. Through part of the distance the shore gravels have probably been removed, and elsewhere the dump of quarry rubbish has covered up the beach; locally the shore line was registered by a cliff in the sandstone which has been quarried. I have mapped shore gravels and one lagoon near these quarries at an altitude, according to the topographic sheet, at least 10 feet higher than the Maumee level elsewhere. It is very likely that a slight error has been made here in sketching the topography. In texture, the entire length of this beach east of the Vermilion River is prevailingly fine.

LOWER MAUMEE

As already suggested, it is impossible at some points to distinguish the two Maumee levels. This condition is due largely to dune deposits, though post-glacial weathering may be a contributing factor.

Extending eastward from the rock hills near Berlin Heights the shore line of the lower Maumee level forms a distinct ridge to the vicinity of Ogontz; within this distance are two short spits which developed from cusps. Just east of Ogontz the two shore lines blend because of a cusp built out from the higher level, to which the lower beach was joined, the difference in level having been rendered less distinct by wind deposits. From this point, the lower Maumee beach bears northward; through part of the distance it is a little over a quarter of a mile wide, and consists mostly of very coarse material. The 750-foot contour outlines the beach until it turns again eastward. At the angle of the turn there is a spit, separated from the shore proper by a lagoon. Post-glacial drainage has cut through the beach just east. Continuing as a single ridge (fig. 2B), it is followed by a highway to the edge of Chappel Creek. In this area a small bay marked the lower Maumee level as is shown by the turn in the beach as well as by a spit, about one-quarter mile long, built eastward from this angle.

On the east side of Chappel Creek the lower shore line for a distance of about one and one-half miles is followed by a highway and is parallel to the beach of the upper level. An off-shore barrier, about one-half mile long, shows in this distance. Both beach ridges have been cut by Sugar Creek, east of which the same parallel relationship persists.

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[5] Pp. 101–117.

After crossing Darby Creek the lower shore line is not distinct. Through part of this distance the Berea sandstone has a cliff which may represent wave-work, but it is not sufficiently continuous to warrant so mapping. It is evident that here the lower level was made irregular by a cape extending nearly a mile into the lake. A beach ridge on its eastern side is continuous to the promontory of Berea sandstone in which the cape terminated. Extending a short distance to the southwest from the promontory there is also a strong beach ridge which terminates in a hook bent to the east. This relationship suggests that the promontory, in which the cape terminates, may have been an island early in the Maumee level, and that as the lake level fell it was tied to the shore line, the bar becoming a beach ridge. North of Axtel, wave-work cut a cliff in the Berea sandstone (fig. 2C); the cliff phase continues southeastward along the beach ridge; this ridge has a sharp development as it trends to the south (fig. 2D). Shortly it turns more directly east, decreasing in height as it nears the river.

On the opposite side of the Vermilion river, the lower Maumee level is near to, and parallel to, the earlier shore line. For the first half-mile the two are separated by a long lagoon. There is another lagoon just north of the lower beach, between it and an off-shore barrier.

Eastward there is some indefiniteness in mapping the beach ridge of this lake level. The highway south from Brownhelm crosses two ridges before reaching the shore of the upper level. The first of these ridges consists of too coarse material to permit its interpretation as an off-shore barrier; the second is so fine in texture that it may be a barrier of the higher level, but at its eastern end it blends into a cliff cut in the sandstone, which is probably contemporaneous in origin with the ridge first alluded to. At the next highway a cusp-like deposit of prevailingly coarse beach materials extends for a short distance northward. From this point nearly to the edge of the sheet a highway follows this beach. At the north-south highway it turns southward parallel to the ridge already described.

THE WHITTLESEY SHORE LINE

Lake Whittlesey marks a decline of about 30 feet from the lower Maumee level. Its shore line is generally parallel to the Maumee ridges; and, in the western third of the sheet, very close to them.

In the vicinity of Berlin Heights this shore line consists of a beach ridge, rather coarse in texture. The nearness of a supply of sandstone and the fact that the shore line trends to the southwest, an alignment due to Huron bay on the Sandusky sheet, account in part for the coarse texture. The beach materials become finer as the ridge turns to the east. For a short distance next, its location is not definite, though apparently it is followed by the railroad siding to the stone quarry. Eastward from the quarry the Whittlesey is a well developed beach ridge, and thus continues for about a mile when it becomes a cliff cut around the northern slope of a Berea outlier, the top of which is covered with Maumee sands and gravels.

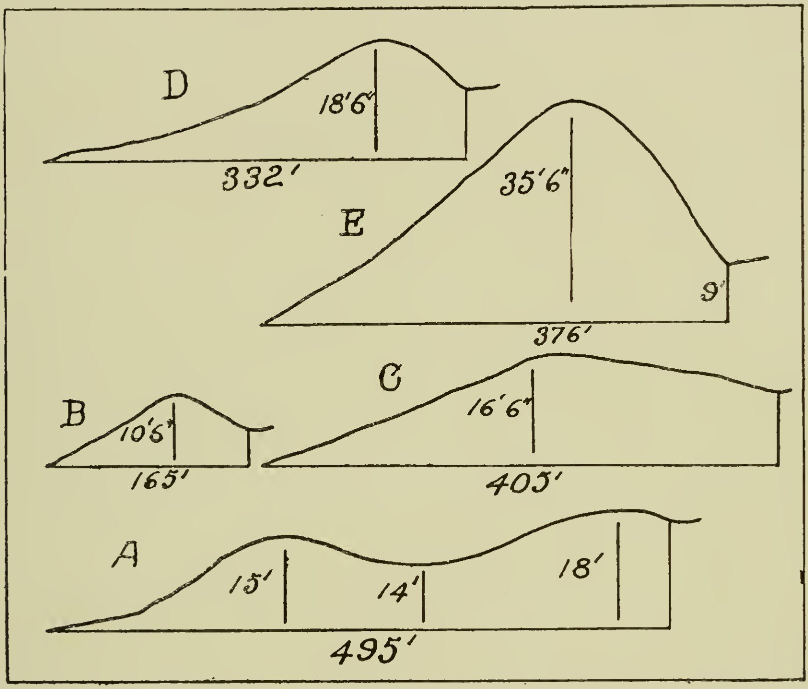

FIG. 2 Consult Fig. 1 for the Location of these Cross-Sections. In Each Case, the Left Side is the Water Slope.

On the east side of Cranberry Creek, the Whittlesey level is defined by a beach ridge trending slightly to the north, for about one and a half miles. Then the shore line becomes a cliff, and bears southward into the Chappel Creek depression. Eastward from this creek, a highway follows the Whittlesey beach to within a short distance of the conspicuous cape of the Maumee level, already described. Through most of this course of three miles, the shore line consists of a typically developed beach ridge; but nearing the east end it becomes a cut cliff. The degree of development of this beach is shown also in the numerous lagoons that border its landward side. Two positions of the shore line are indicated near the cape: the earlier is entirely structural; the later, a short distance north, is cut in the sandstone. Eastward, however, beach gravels prevail almost to the point of the cape. Wave-work of the Whittlesey stage must have cut this cape back some distance; Maumee gravels are found up to the very edge of the cliff.

On the east side of this cape the Whittlesey shore line turns southward, and consists entirely of structural materials. Between the two highways the ridge is coarse in texture. Nearing the eastern of these roads two ridges are shown, separated by a lagoon: the earlier one was of short duration, and registers a southward bend in the lake shore; the later position is a strongly developed ridge, now followed by a highway. The two ridges come together near the Erie-Lorain county boundary. From this point to the gorge of the Vermilion River, the Whittlesey level has a sharply developed beach ridge.

On the opposite side of the river, this beach parallels the river for a distance of about 80 rods; the stream is now removing shore gravels as it undercuts the shale beneath. The beach ridge, as the shore line turns northward, blends into a sandstone cliff; this cape was used as a triangulation station. The highway, eastward to Brownhelm, follows the Whittlesey shore line. In the vicinity of Brownhelm the beach ridge is double.

About one mile east of this place, the earliest course of the shore line extended to the southeast, a position now marked by a low cliff cut into the sandstone; this, however, was a temporary position. Its isolation came about as follows, but the sequence is merely suggestive: east of Quarry Run are two Berea outliers, one of which is almost entirely on the Oberlin sheet: these were islands in the early part of the Whittlesey period; spits were developed from them; the spit reaching to the southwest appears to have been tied first to the shore. Then the Whittlesey shore line from Brownhelm trended northward. The two islands had already been united by bars. A spit grew southward from the one on the Oberlin sheet, eventually tying the islands again to the shore. These outliers, thus doubly tied, formed a cape. The northern shore of the first island, and both the northern and eastern shores of the second island, were cliffed by the Whittlesey waters.

About one-half mile east of Brownhelm, the Whittlesey beach has the most pronounced development noted anywhere on the sheet (fig. 2E). The steep landward slope of this ridge must represent some post-glacial stream erosion.

ISLANDS

In addition to the above islands, which early became a part of the shore line proper, three others are noted. One is northwest of Brownhelm; it was eventually tied to the shore line; the connecting bar is very coarse near the island, but the gravel and cobble become finer southward. On the northern part of this island, was opened one of the earliest Berea quarries in this region.

About a mile west of the Vermilion River, near the Warren shore line is another island of Berea sandstone. This is completely surrounded by beach materials. On its western side successive spits, growing southward, enclosed lagoons as indicated on my map.

Near the east side of the sheet, a spur from the Lake Shore railroad reaches a quarry one mile north. This quarry is in an outlier of the Berea, the top of which was slightly above the Whittlesey level; it bears a ridge of gravel, but I did not note any cliff-cutting.

The Warren Shore Line

Lake Whittlesey dropped 40 feet in the change to the Warren level. Its shore line across half of the sheet is a cliff cut in the Berea sandstone. This cliff-phase is without interruption for the first three miles from the western edge of the sheet; then a cusp of sand extends a short distance northward. Thence to the east is a mile of sandstone cliff which is varied at the next highway-crossing, directly south of Ashmont, by a ridge of fine materials, originating apparently as a barrier but later forming a beach. From this point to Chappel Creek a cliff-phase marks the Warren level. Eastward from Chappel Creek for most of the distance to Sugar Creek, I have mapped an upper slightly developed ridge blending at the western end with a lower and better developed beach ridge. Eastward from Sugar Creek for nearly three miles a cliff continues. This cliff is particularly sharp directly opposite the cape that existed during both the Maumee and the Whittlesey levels. Between this point and the Vermilion River I have indicated two continuous beach ridges, the upper one of slighter development; their continuity is evidence of successive levels. The lower one may have had its origin in an off-shore barrier, but it served as the beach ridge proper for a longer period than did the upper one.

East of the Vermilion two corresponding ridges exist for one and one-half miles. The inner ridge is irregular at one point, suggesting a cusp development. For part of the distance the outer beach is also composite. Near the river channel I noted deposits apparently representing the growth of spits into the slight bay that preceded the static position of the outer beach.

East of Brownhelm Creek the Warren level is registered by a cliff cut in the Berea outlier which was an island, already described, in the Whittlesey stage. Between this outlier and the one near the eastern edge of the sheet two ridges persist, but they are so close together that I am inclined to regard them as a single beach. Obviously, however, the outer one is a little lower in altitude, and its water-slope, for part of the distance, shows steepening by wave-work. Near the eastern outlier the sand is evidently wind-drifted.

ISLANDS

This outlier was an island in the Whittlesey stage, but of slight area, as already explained. Early in the Warren level it was also an island; later it became a part of the shore line. I have not indicated a position for the beach when this outlier was an island; the area immediately southwest bears so much wind-drifted sand that it is impossible to tell where the original beach may have been. My mapping gives the final position of the Warren waters. Practically the whole circumference of the island shows cliff-cutting; the cliff along the eastern side is continuous southward, and for most of the distance is a bare rock wall; but just as the shore line swings to the east it becomes beach material, consisting of fine gravel and sand. The outer slope of this beach has been steepened in harmony with the cliff north of it.

Geographic Influence of these Shorelines

The beaches of these former lakes have been factors in the settlement and development of this area, as well as in its occupation by the forerunners of the white man.

HIGHWAYS

As elsewhere in northern Ohio, these ridges carry highways. The proximity of the beaches on the Vermilion sheet accounts for some of the east-west highways being unusually close together. Commencing on the east side of the sheet, each ridge is followed by a road to the Vermilion river. West of the river the Warren shoreline consists almost entirely of a cut cliff; the other two shorelines carry roadbeds except for a few short intervals. The advantages of this use of old shorelines are obvious; a gravel pike is already made, insuring fairly good drainage; furthermore, the same conditions are of advantage to man in locating his dwellings.

AGRICULTURE

Wherever specialized agriculture is in vogue, the influence of these former lake levels on farming is more obvious. This condition, however, does not arise early in the development of an area; proximity to large cities leads to intensified farming. No large cities are very near the Vermilion sheet. The only conspicuous response is fruit growing; hundreds of acres of sandy soil, both the old ridges and their terraces and the adjacent inland areas over which wind has drifted sand, are being devoted to peach orchards. In recent years some progress has been made in truck farming; this is a response to the two electric lines that afford quick and frequent service to several growing cities. Neither of these electric lines follows the shore ridges, although they are within convenient distance, one north and the other south. The numerous muck areas, noted especially along the Maumee and Whittlesey shorelines, are adapted to market gardening.

ECONOMIC MINERAL PRODUCTS

To some extent these former water bodies have been factors in making the Berea sandstone more accessible. The principal quarry areas now being worked are (1) near Berlin Heights, and (2) southeast of Brownhelm; the latter is generally known as the "Amherst" quarry. Near Berlin Heights the quarry is located in a cliff of the Whittlesey level; this is the older of the two quarries, but the stone does not appear to be as satisfactory as that from the Amherst area. The first Berea sandstone quarry in this part of the state was opened south of Brownhelm station; a crack from the Lake Shore and Michigan Southern Railway afforded good shipping facilities; later, stone of better quality was found elsewhere and this quarry was abandoned. Perhaps the most extensive quarries now being worked in the Berea sandstone are those at Amherst; at no other place in Ohio has such a thickness of the Berea been operated. The structural conditions of this rock horizon are here best suited for quarrying.

The abundant gravel and sand of these shorelines will lead to an increasing local use of cement in making building and other structural blocks, as lumber becomes higher in price. Already one notes the beginning of this use.

The north-south highways, within easy reach of the old beaches, for decades have been coated with the gravel from the shore ridges. At two points, one near Berlin Heights, the other near Ogontz, railroads have removed many acres of beach gravel for ballast.

THERMO-ELECTRIC COUPLES[1]

A. W. Davison

Seebeck discovered the phenomenon of thermo-electricity in 1821. He arranged a series of the metals, the current proceeding through the cold junction in the following order: Antimony to iron, zinc, silver, gold, tin, lead, copper, platinum, bismuth. He also determined that when three or more metals, A, B and C, are in the series, E being the voltage generated, $E_{AC} = E_{AB} + E_{BC}$. In other words, the electromotive force remains the same when a circuit is opened, and a third metal is inserted, provided the temperatures of its ends are the same.

Gaugain found that for any couple, the relationship between the electromotive force and the temperatures can be represented graphically. Kelvin proved these curves to be parabolas, and since the equation for a parabola is $y = ax + bx^2$, in the case under consideration, $E = bt + ct^2$.

Inversion. Since these curves are parabolas, a maximum point, the neutral point, as A (fig. 1), will be reached. For temperatures above this point, the electromotive force will decrease, until t_1 and t_2 are equidistant from, and on opposite sides of, the neutral point, when the electromotive force is zero.

If t_2 is now increased, the electromotive force will be reversed, and "thermo-electro inversion" takes place, the current flowing in the opposite direction. This was proved experimentally by Cumming. Hence from the equation the electromotive force is zero when $t_1 = t_2$, or when $(t_1 + t_2)/2 = -b/2c$.

Thermo-electric power. If we take a lead-metal $(Pb - M)$ couple, whose $E_0^t = bt + ct^2$, and raise t to $(t + dt)$, then $E_0^{t+dt} = b\ (t + dt) + c\ (t + dt)^2$. Now the small electromotive force generated, $dE = E_0^{t+dt} - E_0^t = b \cdot dt + 2ct \cdot dt$.

Thus the rate of increase of electromotive force with temperature $dE/dt = b + 2ct$, is called the thermo-electric power of the metal *M* with respect to lead. It is apparent that this is a straight line, and since the lead line is horizontal, we take it as the reference line, and plot the thermo-electric powers of metals with respect to the lead line.

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[1] A thesis presented for the Fletcher O. Marsh Prize in Physics, Denison University, June, 1910.

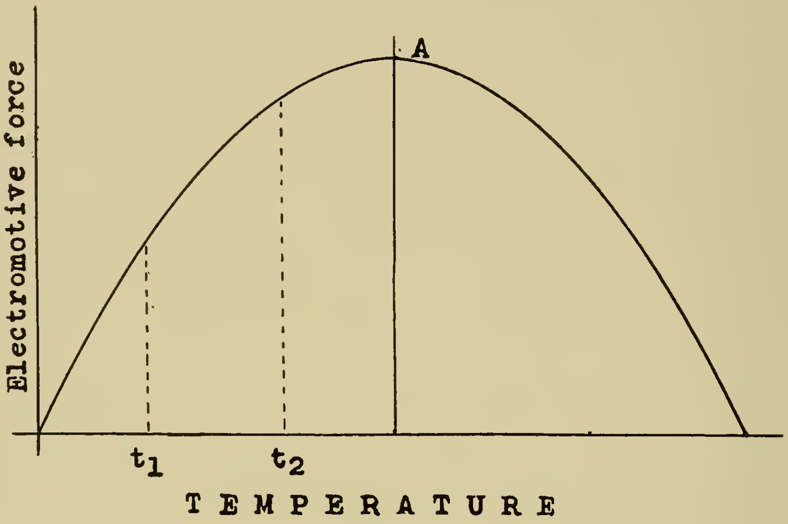


Fig. 1

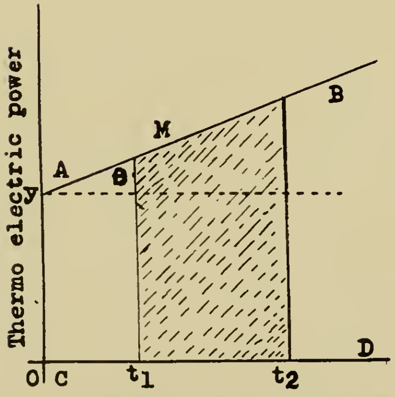

Thermo electric power
A
M
B
θ
y
D
O
C
t_1
t_2
TEMPERATURE

Fig. 2

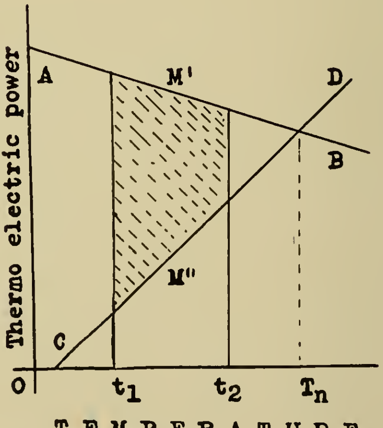
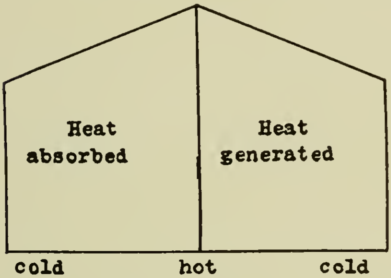

Thermo electric power
A
M'
D
B
M''
C
O
t_1
t_2
T_n
TEMPERATURE

Fig. 3

Thermo-electric diagram. In fig. 2, let *CD* be the standard lead line, and *AB* be the thermo-electric power line of metal *M*. The constant *b* represents the distance *Oy*, while 2*c* is the tangent θ. If $2c$ is negative, the line will slope downward from left to right.

If the junctions are at t_1 and t_2, the shaded area, fig. 2, represents the electromotive force around the circuit, hence for metals M' and M'' fig. 3, the shaded area represents the electromotive force when the junctions are at t_1 and t_2. The ordinate, T_n of the point where the lines cross represents the neutral temperature for those metals. It is customary to represent the thermo-electric power lines of all metals on one sheet, from such a sheet the direction and values of electromotive forces for given temperatures and given metals, as well as neutral points, may be determined.

Peltier effect. Peltier, in 1834, observed that this thermo-electric effect is reversible, that when a current is sent around a circuit whose junctions are at the same temperatures, heat is absorbed at one junction, and generated at the other. This may be explained by assuming that there is a sudden change of potential at the junctions, which is independent of the battery, and that the current does work in traversing this fall of potential.



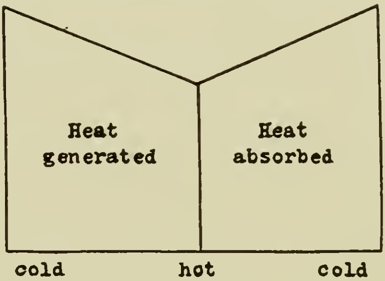


Fig. 4. Thomson Effect. Positive effect. Direction of Current.⟶ Direction of heat travel.⟶

Fig. 5. Thomson Effect. Negative effect. Direction of Current.⟶ Direction of heat travel.⟵

Thomson effect (figs. 4 and 5). Lord Kelvin, while trying to apply the reversible cycle of Carnot to the Peltier effect, concluded that were the Peltier effect the only reversible effect in the circuit, the electromotive force of the couple would be directly proportional to the difference in temperature of the junctions, which is contrary to observed facts. This led him, in 1851, to predict the existence of other effects, which he found, and which were named after him, the Thomson effect.

When a current is sent through a conductor whose center is at a higher temperature than the ends, "electrical convection of heat" takes place, in those metals whose thermo-electric lines slope downwards from left to right, the heat travels against the current; while in those whose lines slope upwards, the heat travels with the current.

This transfer of heat is also sometimes called the "specific heat of electricity."

Thermo-dynamics. Fig. 6 is a diagram of a $M-Pb$ couple, with junctions at t_1 and t_2. The area of $P_2OT_2A_2$ represents the energy gained at the hot junction; the area $P_2P_1A_1A_2$ is the energy lost in the M wire due to the Thomson effect; while of course in the lead wire no energy is lost or gained. The area $P_1O\ T_1A_1$ represents the energy lost at the cold junction, due to the Peltier effect. It is therefore apparent that the area $A_1T_1T_2A_2$ represents the total gain of energy when unit quantity of electricity flows around the circuit.

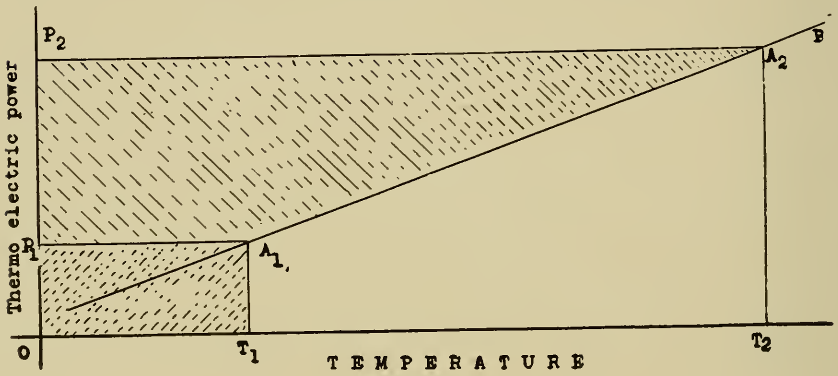


Fig. 6

From the diagram, it is also apparent that the electromotive force of any couple between t_1 and t_2 is equal to the $EMF_{\theta}^{t_1}$ + $EMF_{t_2}^{\theta}$. This is called the law of successive temperatures.

Effects of strain, irregularities, etc. Magnus has shown that a circuit of one metal, uniform in state and strain, can have no thermo-electric force, no matter at what temperatures its junctions may be; but impurities, variations in physical condition, strain, alter the effect, even change the series of Seebeck. Different grades of iron and steel show great variations, and many metals give unstable curves under high temperatures.

Alternate hard and soft places, the least oxidation of surfaces, strain, twisting, bending, shear; all contribute to variations, some to a great degree.

The cause of thermo currents. Until the advent of the electron theory, the phenomena of thermo-electricity were without explanation, since it was definitely known that there is no exchange of atoms between the metals. But the electron theory gives a very good explanation of the observed facts.

Let us consider an electron; the best assumptions of J. J. Thomson attribute it to be $\frac{1}{1700}$ of the mass of a hydrogen atom, while the repelling force exercised between two electrons is 10^{43} times greater than the gravitational pull exercised by the same masses. Each electron is a negative charge of electricity, and we consider that when a univalent molecule has two electrons attached, it carries a negative charge; when one, a neutral charge; when none, a positive charge.

The modern view of heat is that it is a rapid motion of the smallest parts of matter, that is, of these electrons, and it has been determined that to raise the temperature of a wire from 0° to 100°, increases the velocity of its electrons 17 per cent.

Just as the pressure of a gas is increased by heating, the "pressure" of the electrons is increased by heating, and they travel into cooler parts, where the "pressure" is less.

When a wire is bent and joined, forming a circuit, and a point of this wire is heated, the electrons move in opposite directions from the hot point; but no current results, since they go in both directions. If, however, the wire on one side of the hot point is cooled, the slope of pressure will be abrupt on that side, and the electrons will pass in that direction. When a thermojunction is made, the "slope of the heat curve" is altered by joining two metals of different conductivities for heat. If bars of lead and zinc are joined, and the union is heated, this temperature slope is more abrupt on the lead side, so the electrons will pass from zinc to lead. Since these electrons are negative charges, the current of positive electricity is said to pass from lead to zinc.

On the other hand, if a current is sent across a cold junction, the electrons passing from zinc to lead, since there is more resistance in the lead than in the zinc, the electrons must acquire energy from somewhere, which they do from their motion, hence the junction is cooled. It is at once apparent how, if the electrons are traveling from lead to zinc, the junction will be heated.

But how may we explain thermo-electric inversion, and the neutral point?

Liebenow found that the greater the ratio:—conductivity of heat to conductivity of electricity, the more readily electrons pass from a metal across the hot junction. Also, that "there is an electromotive force generated within the metal which urges the electrons to proceed in the direction in which heat is being propagated." So the electromotive force of a thermo-couple is a differential effect, due to more electrons being dragged along in one metal than in another.

Explanation of neutral point and inversion. In one metal, at definite temperatures, the electromotive force is proportional to $\sqrt{L/S}$, where L is the heat conductivity, and S the electrical conductivity. Now L does not usually vary greatly with temperature, but it is well known that electrical conductivity does; and it is this very thing which causes thermo-electric curves to be other than straight lines, and which causes thermo-electric inversion.

Now in the majority of metals, the quantity $\sqrt{L/S}$ increases with rise in temperature, but in some, as in iron, the ratio diminishes, or reverses upon heating; and the couple passes through a maximum, or is reversed.

For an efficient thermo-couple, two metals are desired whose ratios $\sqrt{L/S}$ are as different as possible, for if as the temperature changes, these ratios become equal, the wandering of the electrons will be the same in both directions, and the neutral point will be reached.

THE DETERMINATION OF THE THERMO-ELECTRIC CHARACTERISTICS OF SAMPLES OF WIRE OBTAINED FROM THE DRIVER-HARRIS WIRE COMPANY

In determining these characteristic quantities, Leeds and Northup Research galvanometer No. 323, and L. & N. Standard Laboratory Wheatstone Bridge No. 5034 were used. To alter the sensibility of the galvanometer, so that various maximum electromotive forces might be determined, the resistance box was connected in series with the galvanometer and thermocouple, and by means of this resistance, suitable sensitiveness was obtained.

Standardization of galvanometer (fig. 7). In order to be able to determine electromotive force by means of a galvanometer it was standardized by the "fall of potential" method, as follows:—

A primary circuit was made up of (1) a source of electromotive force (dry cell), (2) an adjustable resistance, *r* (3) a milliammeter. (4) a known resistance, *R*, such as a bridge wire, or standard ohm.

The terminals of the galvanometer circuit including the "adjusting resistance" *S* were connected across *R;* then for a given current *I* flowing around the primary circuit, the electromotive force acting on the galvanometer circuit is equal to $R \times I$.

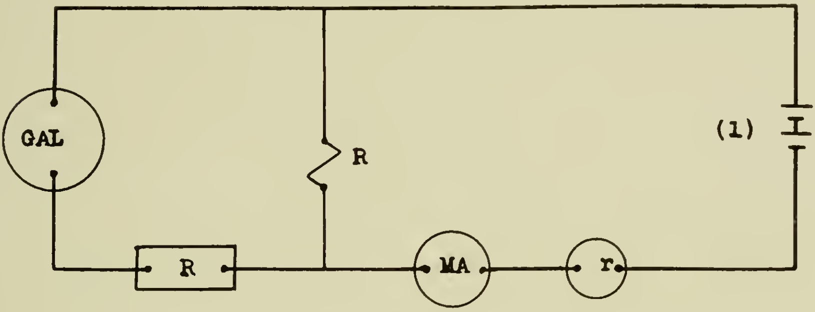


Fig. 7. Arrangement for standardizing galvanometer.

By adjusting *r* various values of *I* are obtained, hence various electromotive forces.

Results were recorded as follows:

(a) (b) (c) (d)

Amperes (M·A) Deflection (*G*) *EMF* [(a)×*R*] Volts per mm. [(c)/(b)] (a) and (b) are obtained from readings of instruments *MA* and *G;* (c) is obtained by multiplying (a) by the resistance *R;* and (d) is found by dividing (c) and (b). Example: Resistance $R = .444$ ohm.

(a)	(b)	(c)	(d)
.00268	25mm.	.001189	.0000476

Now, the electromotive force of any thermo-couple acting is at once obtained by multiplying the deflection of the galvanometer by the factor (d).

Since the electromotive force of different couples varies widely, a number of values of S were used, and the galvanometer standardized for each one. The following values of S were used: 0, 350, 600, 2100, 5000, and 6000 ohms.

Method. The terminals of the thermo-couple were connected to the galvanometer, with the box S in series, as per fig. 9.

In order to insure that the only thermo-electric effects in the circuit were those to be measured, three junctions were used, Cu-M' (e); M'-M'' (f); and M''-Cu (g). The junctions (e) and (g) were maintained at 0°, and (f) was raised to various values of t By recording the temperature of (f), and the deflections of the galvanometer, the various electromotive forces of the circuit may be determined, and curves plotted.

Junctions (e) and (g) were placed in separate kerosene baths, and these baths placed in the same ice-bath. This separation of the baths was effected to overcome any galvanic current that might be set up. Kerosene was used, since it does not corrode the metals.

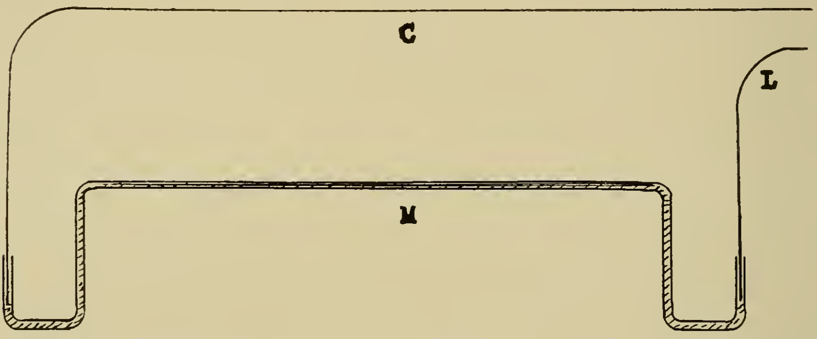


FIG. 8. C is a copper wire to the galvanometer; L, a lead wire, M, a glass tube containing mercury.

Junction (f) was heated in a bath of heavy lubricating oil, which is non-corrosive, and is not volatile at the temperatures used.

In order to null thermo-effects at the various junctions (or rather connections) of the system, the junction (f) was first maintained at 0° by placing it in a third bath similar to those of (e) and (g), and "setting" the galvanometer at zero. These other thermo-effects were due to a number of causes, radiation from the body, from an incandescent lamp used for lighting the scale, etc.

Errors, which were afterward remedied, were introduced into the first few sets of readings taken, due to the following causes:

(a) The coil of the galvanometer was not hung in a uniform magnetic field, this was discovered in calibration.

(b) When the temperature was gradually raised, and after the flame had been removed, the deflection of the galvanometer would reach a maximum, and decrease, before the thermometer had reached its maximum. This "time drag" was due to the fact that glass, being a poor heat conductor, did not transmit heat to the mercury as rapidly as heat was transmitted to the couple.

(c) A great amount of trouble was encountered in getting a suitable method of joining the elements, *i. e.*, of producing the junctions themselves. The following methods were tried:

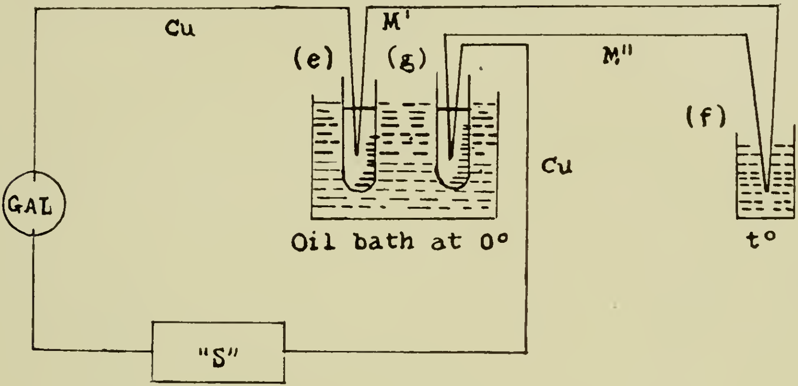


FIG. 9. Arrangement for measuring electromotive forces.

(1) Simple twisting. This scheme proved very satisfactory when the junction was wanted for immediate use; but after a few hours the results varied, due to corrosion, the metals oxidizing even where they were twisted the tightest.

(2) Soldering the wires. The use of solder in itself does not necessarily alter the thermo-electric effect, since from the law of intermediate metals, the electromotive force is not changed by the introduction of a third metal. But the flux necessary for soldering has a chemical effect whose thermo-electric characteristics are different. The presence of a mass of solder also tends to give a shunt across the junction, which permits the return of current.

(3) Fusing in an electric arc. By using a carbon block for cathode, and twisting the wires, then using the junction for anode, a current will melt the metals, and make an excellent junction. This scheme was finally resorted to for all the junctions except the *Pb-M* ones.

(4) For *Pb-M* junctions, a very satisfactory union was effected by melting the lead in a Bunsen flame, and joining the other metal in this way.

(5) In the case of the lead-mercury element, the *Hg* was contained in a tube of the form shown in fig. 8. The lead was cleaned, and inserted into the mercury in one end, and the copper line was inserted in the other end. Considerable caution had to be exercised to keep the lead from amalgamating, but by preparing a fresh specimen each time, this greatest difficulty was overcome.

Results of measurements of an advance lead thermo-couple (fig. 10). Current goes from Advance to lead in the hot junction. Junctions (e) and (g) at 0°; *S* = 5000 ohms, so (d) = .00004864 volts per mm.

(1) TEMPERATURE (*f*)	(2) DEFLECTION GALVANOMETER	(3) *EMF.*
0.0	0.0	.0000000
16.0	23.6	.0005275
35.0	32.1	.0011505
47.0	43.2	.0015665
73.0	51.4	.0025090
109.0	89.5	.0043550*
130.5	101.6	.0049500
141.0	108.6	.0052850
166.0	132.7	.0064500
183.2	147.8	.0072050
195.0	158.7	.0077300*
209.5	170.8	.0084100
221.2	189.9	.0092400
233.5	195.9	.0095400
243.3	206.6	.0100600
250.0	217.6	.0105800
262.0	230.8	.0112400
270.0	239.0	.0116400*
276.5	245.8	.0119600
283.0	252.2	.0122900
292.0	262.7	.0128300

Those readings marked with an asterisk were afterward checked by means of the potentiometer.

The resistance of this thermo-couple, with its copper leads was .74 ohm, so that, in comparison with the high resistance, S, it does not need to be taken into consideration.

Determination of the constants b and c.

(from the equation $E = bt + ct^2$)

$E_0^{35} = 35b + 1125c = .0011505$

also $E_0^{250} = 250b + 62500c = -.01058$

Solving these equations for b and c,

$b = 31.33 \times 10^{-6}$

$c = 4.39 \times 10^{-9}$

Advance manganin thermo-couple (fig. 11). Current goes from advance to manganin in the hot junction. Junctions (e) and (g) at 0. S = 5000 ohms. So (d) = .00004864 v.p. mm. Resistance of couple, and copper leads, .97 ohm.

(1) TEMPERATURE OF (*f*)	(2) DEFLECTION OF GALVANOMETER	(3) *EMF.*
0.0	0.0	.000000
17.0	12.2	.000596
26.5	19.0	.000927
80.0	63.2	.003076
126.0	99.1	.004821
143.0	113.1	.005520
163.5	130.4	.006360
188.3	152.0	.007210
199.5	163.1	.008000
225.0	189.2	.009220
241.0	205.9	.010020
258.5	224.3	.010930
269.0	235.5	.011460
278.0	245.6	.011980
287.0	258.2	.012600

$E_0^{80} = 80b + 6400c = .003075$

$E_0^{225} = 225b + 50825c = .009220$

From which equations,

$b = 29.65 \times 10^{-4}$

$c = 17.325 \times 10^{-9}$

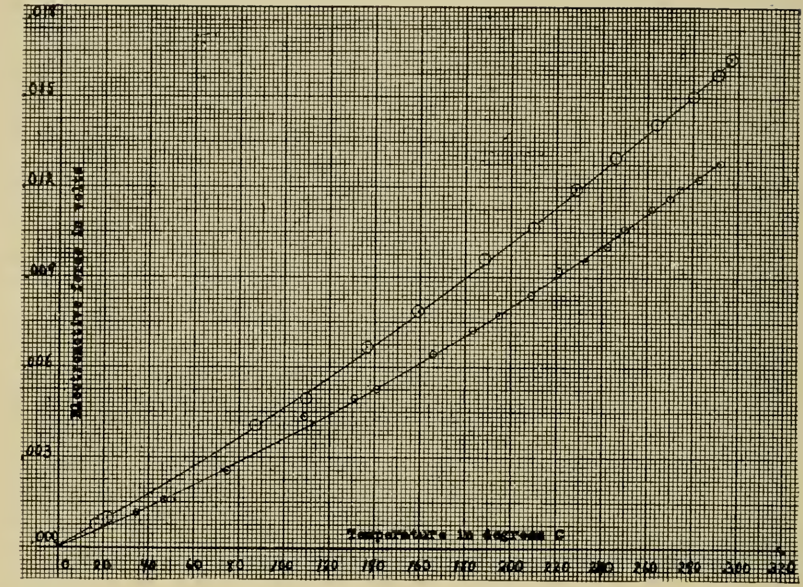


FIG 10. Upper curve, Advance-Iron junction: Lower curve, Advance-Lead.

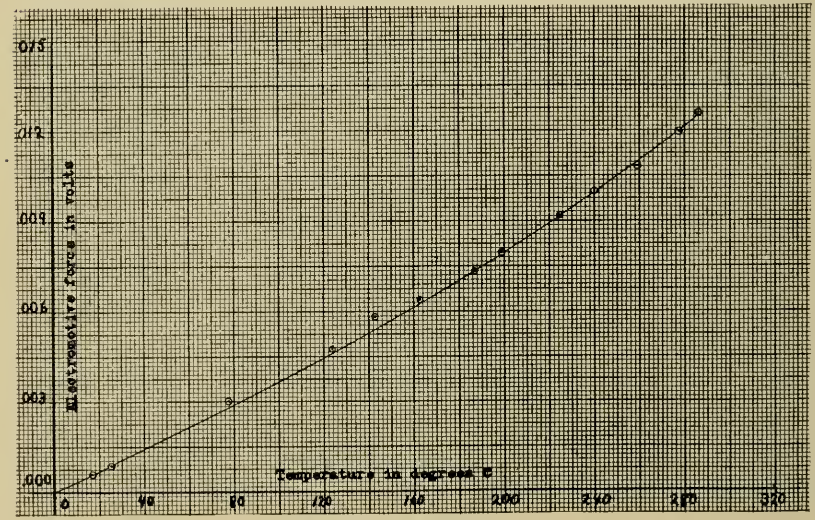


FIG. 11. Curve for Advance-Manganin Junction.

Advance iron thermo-couple (fig. 10). Resistance, .734 ohms. Current goes from advance to iron in the hot junction. Junctions (e) and (g) at 0. $S = 6000$ ohms. So (d) = .00006177 volts per mm.

(1)	(2)	(3)
0.0	0.0	.000000
17.0	12.6	.000780
19.8	14.1	.000872
22.0	16.3	.001008
87.7	65.6	.004050
111.0	80.6	.004970
137.0	108.5	.006690
159.2	127.7	.007890
188.7	155.8	.009610
210.0	175.7	.010680
229.1	193.5	.011970
246.5	210.6	.013000
265.4	229.7	.014170
280.6	244.6	.015070
291.0	254.6	.015770
297.0	261.4	.016160

From $E_0^{137} = 137b + 18769c = .00669$ and $E_0^{297} = 297b + 88209c$ $= .01616$

$b = -6.4 \times 10^{-6}$

$c = 40.42 \times 10^{-8}$

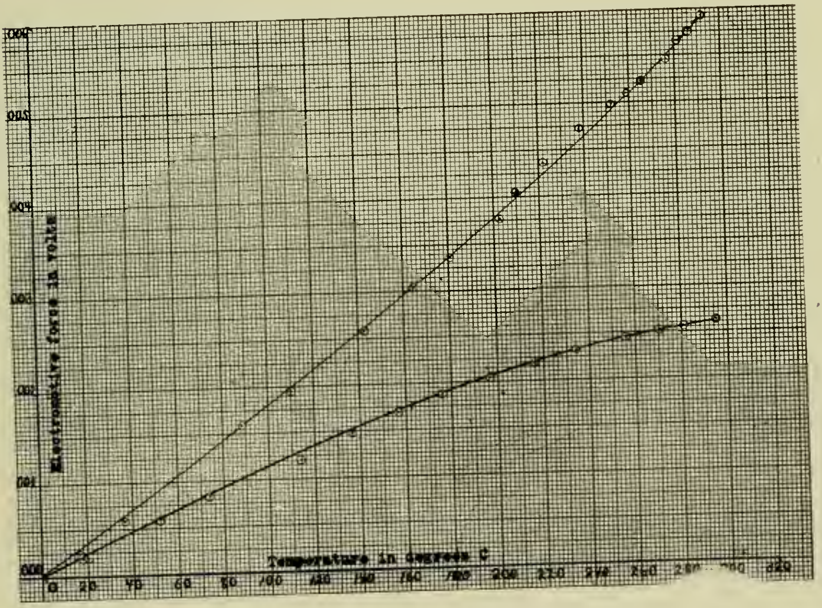


FIG. 12. Upper curve—Nickel-Lead Junction. Lower curve—Iron-Lead Junction.

Lead-Nickel couple (fig. 12). Resistance, .193 ohm. Current goes from Nickel to Lead in the hot junction. Junctions (e) and (g) at 0. S = 2100 ohms, so (d) = .00002383.

(1)	(2)	(3)
0.0	0.00	.0000000
17.6	10.37	.0002465
36.5	24.37	.0005805
88.7	68.67	.0016365
110.0	81.97	.0019515
143.2	109.57	.0025815
165.0	127.97	.0030465
181.0	141.57	.0033715
203.0	157.47	.0037565
210.0	170.17	.0040565
222.0	183.57	.0043765
238.0	198.37	.0047265
252.0	209.37	.0049965
259.0	214.50	.0051066
265.0	219.40	.0052461
276.0	228.50	.0054663
281.5	237.40	.0056565
286.0	241.20	.0057467
291.5	243.90	.0058215

Measurements of this junction by the potentiometer gave the following results: 110°, .0020137; 245°, .0049305.

Values of B and c taken from the readings at 110 and 252 degrees, are:

$b = -16.125 \times 10^{-6}$

$c = -14.69 \times 10^{-9}$

Iron Lead Couple (fig. 12). Resistance, .96 ohm. Current goes from lead to iron on the hot junction. S = 599 ohms. (The value of S + the resistance of the couple = 600 ohms). Junctions (e) and (g) at 0. Since res. = 600, (d) = .0000102814 v. per mm.

(1)	(2)	(3)
0.0	0.	.0000000
18.0	18.5	.0001900
20.5	19.0	.0001951
52.0	60.5	.0005975
74.0	85.1	.0008375
114.0	116.5	.0012000
137.0	144.0	.0014840
157.1	164.7	.0016940
176.0	181.3	.0018690
197.0	197.7	.0020350
216.0	211.2	.0021810
234.0	224.1	.0023100
256.0	237.7	.0024450
271.0	245.6	.0025300
281.0	250.8	.0025800
295.5	254.9	.0026250

$$E_0^{18} = 18b + 324c = .00019$$
$$E_0^{216} = 216b + 46656c = .002181$$

From which

$$b = 10.787 \times 10^{-6}$$
$$c = 12.875 \times 10^{-9}$$

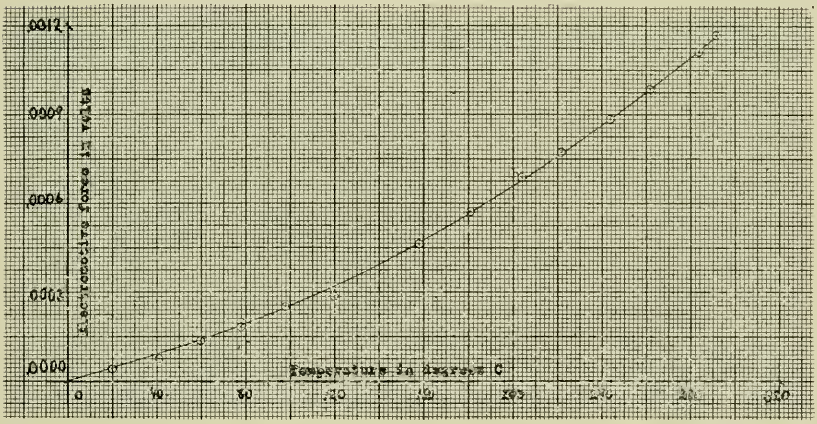


FIG. 13. Curve for Mercury-Lead Junction.

Mercury Lead couple (fig. 13). Current goes from mercury to lead in the hot junction. Junctions (e) and (g) at 0. $S = O$ so (d) = .000003133 v. per mm. *, $S = 350$ so (d) = .00005274 v. per mm.

(1)	(2)	(3)
0.0	0.0	.0000000
20.5	11.7	.0000367
41.5	27.0	.0000847
60.5	43.2	.0001352
78.5	60.7	.0001900
98.0	81.5	.0002555
120.0	92.0	.0002880
157.8	149.2	.0004675
182.8	185.0	.0005795
204.0	222.3	.0006980
222.5	147.0	.0007740
*244.0	169.8	.0008900
*262.9	189.0	.0009970
*282.0	214.3	.0011280
*292.0	224.8	.0011810

$$E_0^{93} = 98b + 9604c = -.0002555$$

$$E_0^{244} = 244b + 59506c = -.0008900$$

From which

$$c = -71.33 \times 10^{-10}$$

$$b = -19.8 \times 10^{-7}$$

Climax Lead couple (fig. 14). Resistance, 1.08 ohms. Current goes in the hot junction from the climax to the lead. S = 349 ohms, so that effective value of S = 350 ohms, so (d) = .000005274 v. per mm. Junctions (e) and (g) at 0°.

(1)	(2)	(3)
19.0	9.0	.0000475
67.0	30.0	.0001583
85.0	37.0	.0001955
113.0	48.0	.0002535
135.0	56.3	.0002976
150.0	62.0	.0003270
165.0	67.0	.0003540
178.0	71.8	.0003790
189.0	75.7	.0003990
203.0	80.0	.0004220
214.0	83.5	.0004410
221.0	85.5	.0004510
233.5	89.0	.0004690
241.0	90.8	.0004790
251.5	94.0	.0004960
263.5	97.2	.0005120
277.0	101.0	.0005320
287.0	103.1	.0005430
302.0	103.6	.0005450
305.5	106.0	.0005600

$$E_0^{85} = 85b + 7225c = .0001955$$
$$E_0^{150} = 150b + 22500c = .0003270$$

From which

$$b = -14.8 \times 10^{-7}$$
$$c = 46.5 \times 10^{-10}$$

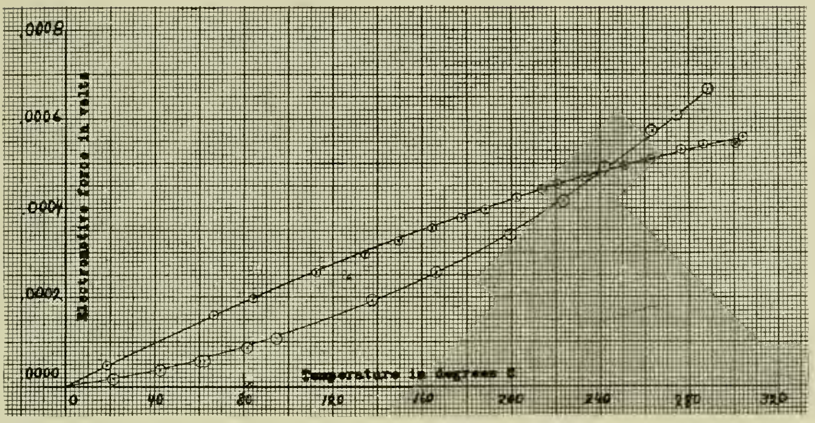


FIG. 14. Upper curve, Climax-Lead Junction. Lower curve, Lead-Manganin

Lead Copper couple (fig. 15). Resistance, .01 ohm. Current goes from lead to copper in the hot junction. Junctions (e) and (g) at 0. S = 350 ohms, so (d) = .000005274 v. per mm.

(1)	(2)	(3)
0.0	0.0	.0000000
21.0	9.6	.0000505
68.0	33.6	.0001777
100.0	53.0	.0002790
128.0	71.2	.0003750
145.0	83.2	.0004380
192.0	120.8	.0006370
220.0	144.0	.0007580
246.0	167.5	.0008810
254.0	175.0	.0009220
275.0	198.0	.0010410
299.0	222.0	.0011700
316.2	242.0	.0012730
260.0	183.0	.0009630
240.0	164.5	.0008670
149.0	89.0	.0004680

$$E_0^{128} = 128b + 16384c = .000557$$
$$E_0^{243} = 243b + 59049c = .000491$$

From which

$$b = 1.2 \times (10)^{-7}$$
$$c = 13.58 \times (10)^{-9}$$

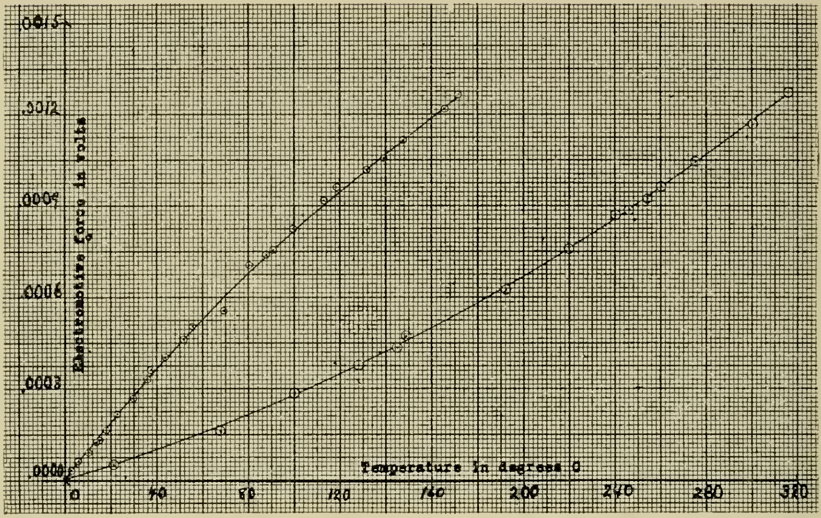


Fig. 15. Upper curve, Iron-Copper Junction. Lower curve, Copper-Lead.

Lead Manganin (fig. 14). $S = 0$. so (d) = .000003133—volts per mm. Junctions (e) and (g) at 0.

Current goes from lead to manganin in the hot junction.

(1)	(2)	(3)
0.0	0.0	.0000000
22.0	5.3	.0000166
43.0	11.7	.0000366
62.3	18.7	.0000587
82.0	27.1	.0000850
60.8	17.9	.0000560
95.0	33.2	.0001040
138.2	61.0	.0001910
167.0	82.5	.0002580
200.0	109.6	.0003420
224.0	133.0	.0004160
243.0	157.0	.0004910
266.0	184.0	.0005760
275.5	195.1	.0006100
289.0	213.2	.0006675

$E^{2} = 82b + 6724c = .000085$
$E^{000} = 200b + 40000c = .000342$ From which
$b = 1623.66 \times (10)^{-8}$
$c = 43.177 \times (10)^{-10}$

Iron Copper Thermo couple (fig. 15). Current goes from copper to iron in the hot junction. S = 4000 ohms, hence (d) = .0000308 volts per mm. (see below). Junctions (e) and (g) at 0.

(1)	(2)	(3)
0.0	0.00	.0000000
3.0	1.00	.0000308
5.8	2.00	.0000616
10.5	3.00	.0000924
13.5	4.10	.0001260
15.2	4.70	.0001445
18.3	5.30	.0001665
24.0	7.10	.0002180
29.6	8.90	.0002740
36.0	10.90	.0003350
38.3	11.80	.0003635
44.0	13.30	.0004090
51.0	15.00	.0004610
56.0	16.70	.0005130
60.0	18.10	.0005570
71.0	20.10	.0006090
80.0	22.90	.0007060
88.0	24.00	.0007400
89.3	24.60	.0007590
98.9	27.00	.0008310
113.7	30.00	.0009230
118.0	30.75	.0009480
132.0	33.50	.0010320
139.5	35.00	.0010780
148.3	36.50	.0011220
166.0	37.90	.0012210
171.85	40.60	.0012530

To determine the constants b and c
$E_0^{24} = 24b + 576c = .000218$
$E_0^{80} = 80b + 6400c = .000706$ From which
$b = 91.94 \times (10)^{-7}$
$c = 4.61 \times (10)^{-9}$

Standardization of Galvanometer. $S = 4000$ ohms.

(a) AMPERES	(b) DEFLECTION	(c) VOLTS	(d) V PER MM.
.0018	26.	.00080	.0000308
.00374	53.1	.00166	.0000312
.00536	75.9	.00238	.0000314
.00778	111.8	.00345	.0000313
.01021	145.5	.00453	.0000313
.01186	173.	.00529	.0000306
.01366	200.	.00609	.0000304
.0154	226.5	.00683	.0000303
.01694	250.	.00750	.0000300

Average = .0000308 volts per mm. of scale of galvanometer.

Construction of the thermo electric power diagram. As stated above, a very convenient method of determining the resultant electromotive force for any two metals at any temperatures consists in plotting the thermo electric power lines of these metals, with temperatures as abscissas, and "electromotive force in microvolts per one degree centigrade" as ordinates. After such a diagram has been constructed, all that it is necessary to do in order to find the electromotive force around a thermo-electric circuit of any metals, M and M', whose junctions are at t_1 and t_2 is to determine the area, with consideration of algebraic signs, enclosed in the quadrilateral composed of the two thermo-electric power lines of the metals, and lines drawn vertically at t_1 and t_2. This electromotive force is of course given in microvolts.

For convenience and simplicity, the lines of all metals are usually drawn upon one sheet, with the lead line, since lead does not show the Thomson effect, as the base line.

Now in drawing these lines, one has only to remember that b represents the ordinate at 0°, while $2c$ is the tangent of the angle between the thermoelectric power line, and the horizontal.

Thus in drawing the line for copper, "b" is equal to 1.2 microvolts, hence a point was located whose coördinates are (0, 1.2) Since "c" = .01358 microvolts, a point was located at 300° whose coördinates are (300, 9.26). The abscissa 9.26 was determined as follows: "c" was multiplied by $2t$ ($= 2 \times 300$) and this result (8.06) was added to 1.2. Now by drawing a line connecting these two points, the thermo-electric power line for copper is complete.

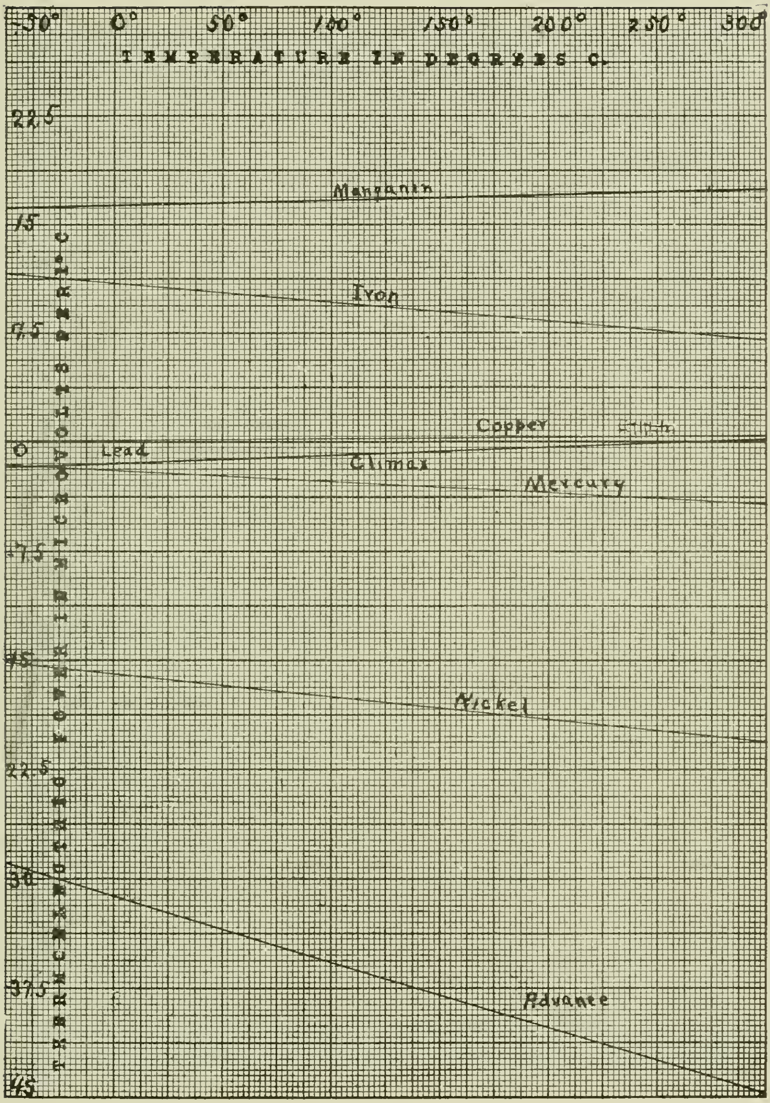


Fig. 16. Thermo-electric power diagram.

The thermo-electric power lines for the remaining metals were drawn in this same manner.

Conclusion. The preceding work was performed primarily with a view to investigating the thermo-electric characteristics of "advance," "climax," and "manganin" substances whose thermo-electric lines are not found on the text-book diagrams. The subsequent plotting of these lines is of no little interest. But as a check, the metals, nickel, mercury, iron, copper, whose lines are well known, were investigated, plotted, and the thermo-electric lines found to agree with existing diagrams within reasonable limits.

Barney Physical Laboratory.

THE MERCER LIMESTONE AND ITS ASSOCIATED ROCKS IN THE NEWARK-ZANESVILLE REGION[1]

Clara Gould Mark

CONDENSED HISTORICAL REVIEW

The Pottsville formation in Ohio consists of the following members, as given by Dr. Orton in the *Geological Survey of Ohio*, vol. vii, 1893, p. 36:

> "Conglomerate group
>   Homewood sandstone
>   (Tionesta Coal)
>   Upper Mercer Group
>   Ore
>   Limestone
>   Coal, No. 3a, Newberry
>   Lower Mercer Group
>   Ore
>   Limestone
>   Coal, No. 3, Newberry
>   Massillon sandstone, upper
>   (Quakertown Coal), Coal No. 2, Newberry
>   Massillon sandstone, lower
>   Sharon Coal–Coal No. 1, Newberry
>   Sharon Conglomerate."

The limestone of the Lower Mercer Group is usually referred to as the Mercer limestone, the name having been first applied to it in 1858 by H. D. Rogers from its exposures in Mercer County, Pennsylvania (*Geology of Pennsylvania*, vol. ii, pt. 1, 1858, p. 476). The occurrence of this limestone in Ohio was mentioned by Charles Briggs, Jr., in the *First Annual Report* of the Geological Survey of Ohio, published in 1838. In the *Second Annual Report,* published later in the same year, Col. J. W. Foster described exposures of the Mercer limestone in Muskingum and Licking counties. Neither Mr. Briggs nor Col. Foster gave any name to the limestone, but referred to it merely as "blue limestone."

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[1] This paper is part of a thesis presented for the degree of Master of Arts in the Ohio State University. The work was done under the direction of Dr. Charles S. Prosser to whom I am greatly indebted for his kind assistance and advice.

In the *Report of Progress in 1869* published in 1870, Professor E. B. Andrews described the occurrence of the Mercer limestone in Muskingum, Licking, Perry and Hocking counties, but owing to an unfortunate mistake in identification by one of his assistants, he called it, with but one exception, the "Putnam Hill limestone." This one exception is in the description of the section at Putnam Hill where the limestone in the bed of the Muskingum is said to be possibly the same as the Maxville (p. 84). In the *Report of Progress in 1870* published in 1871, Professor Andrews continued tracing the line of the Mercer limestone from Hocking County through Vinton, Jackson and Scioto counties to the Ohio River, still calling it the "Putnam Hill limestone" though at times referring to it as the "Blue limestone." In the same volume is an account by Dr. Newberry of exposures of the Mercer limestone and Coal No. 3 which underlies it, in various localities from Coshocton County east to the Pennsylvania line.

Professor Andrews in volume i of the *Geological Survey of Ohio* (1873, p. 317) calls attention to the mistaken use of the name "Putnam Hill" for the Mercer limestone, and gives the correct stratigraphical position of the Maxville, Mercer, and Putnam Hill limestones in Muskingum County. He does not give any name to the Mercer limestone, but describes it as a limestone intermediate in position between the Maxville and Putnam Hill. In volume ii of the *Geological Survey of Ohio*, 1874, pp. 81–180, Dr. Newberry refers to the Mercer limestone a number of times as the "Zoar limestone," but does not give any detailed description of it. Dr. Orton was the first to give a careful description of it under this name (vol. iii, 1878, p. 891). In this account he says that the "Zoar limestone" is the best marked stratum in the Lower Coal Measures of the State, and that it may be followed from the Pennsylvania line across Ohio to the Ohio River. In the Report

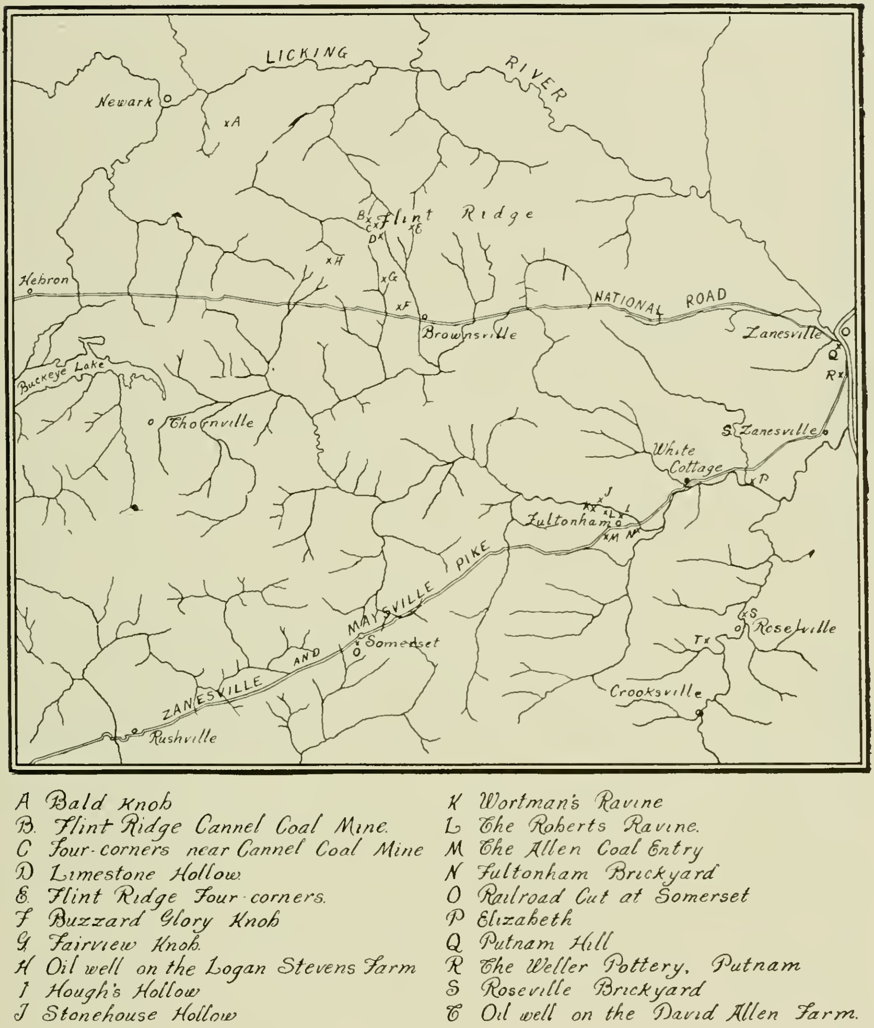
LICKING RIVER
Newark
xA
Flint Ridge
Hebron
NATIONAL ROAD
Brownsville
Zanesville
Buckeye Lake
Thornville
S. Zanesville
White Cottage
Fultonham
ZANESVILLE AND MAYSVILLE PIKE
Somerset
Roseville
Crooksville
Rushville
A Bald Knob
B. Flint Ridge Cannel Coal Mine.
C Four-corners near Cannel Coal Mine
D Limestone Hollow.
E. Flint Ridge Four-corners.
F Buzzard Glory Knob
G. Fairview Knob.
H Oil well on the Logan Stevens Farm
I Hough's Hollow
J Stonehouse Hollow
K Wortman's Ravine
L The Roberts Ravine.
M The Allen Coal Entry
N Fultonham Brickyard
O Railroad Cut at Somerset
P Elizabeth
Q Putnam Hill
R The Weller Pottery, Putnam
S Roseville Brickyard
T Oil well on the David Allen Farm.

Fig. 1. Sketch map of the Newark-Zanesville region.

of the *Geological Survey of Ohio*, vol. v, 1884, pp. 13 and 14, Dr. Orton correlates this limestone with the Lower Mercer of Pennsylvania and describes it at some length.

DESCRIPTION OF LOCAL SECTIONS

The region studied in the preparation of this paper extends from the vicinity of Newark, Ohio, east to Zanesville and south to Somerset and Roseville, and embraces portions of Licking, Muskingum and Perry counties. Particular attention was given to the Mercer limestone as it occurs in this area, and where opportunity afforded the associated rocks both above and below it were also studied to some extent. In the various exposures studied the strata were seen in ascending order from the Maxville limestone at the top of the Mississippian system, through the entire thickness of the Pottsville formation at the base of the Pennsylvanian system, and up to the Lower Kittanning coal in the Allegheny formation.

NEWARK

Bald Knob. Near Newark the Pottsville is the highest formation exposed, and the Mercer limestone is its highest member seen in this vicinity, being found only upon the top of one of the highest hills. This hill, spoken of in the various Ohio reports as Bald Hill, McFarland's Hill, and "the hill above Dr. Wilson's old coal entry," lies about two miles southeast of Newark, and on the topographic map of the United States Geological Survey is called Bald Knob. The crest of the hill is 1220 feet above sea level, and about 400 feet above the level of the South Fork of the Licking River at the Second Avenue Bridge. The following section was measured here:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
5. *Mercer limestone.* The top of the hill is covered with broken blocks of dark blue very fossiliferous limestone which weathers into somewhat shaly fragments. None of the limestone is in place, and the heaviest block seen measured 8 inches in thickness. A small proportion of these fragments are less shaly and when weathered are buff in color and much lighter in weight than the shaly dark blue limestone. They are extremely fossiliferous, but the fossils are, as a rule, not so well preserved as in the blue limestone.		187½
4. Covered to the horizon of the Sharon coal. One hundred feet by barometer below the top of the hill are the remains of "ore diggings" on the eastern side of the hill, where ore has been worked by stripping. Ore is said to have been taken out here about 1850 and shipped to Mary Ann Furnace on the north side of the Licking river in Mary Ann township.	125½	187½
3. *Sharon coal (?).* There is an old coal entry near the house on the west side of the hill. The thickness of this coal is given by M. C. Read in his account of the geology of Licking county as 30 inches. On the north side of the hill are more recent entries where the coal is reported to be 27 inches thick. The coal has not been worked for a number of years and all the openings have fallen in, and there is some uncertainty as to whether they are all in the Sharon horizon.	2½	62
2. Covered interval.	48	59½
1. *Sharon conglomerate.* Coarse-grained quartzose sandstone with layers of conglomerate; light buffy colored, but much of it iron stained and weathered red or red-brown. The pebbles in the conglomerate are small, most of them less than one-fourth inch in diameter, generally but not all white quartz, and cemented rather loosely, so that when the rock is broken the pebbles along the fracture are loosened from the matrix instead of breaking. Base of the Pottsville formation.	11½	11½

The following fossils were collected from the limestone on top of the hill:

Septopora rectistyla Whitfield

Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Edmondia ovata Meek and Worthen
Edmondia nebrascensis Geinitz
Nucula beyrichi von Schauroth?
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Parallelodon sangamonensis
Myalina swallovi McChesney
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten herzeri Meek
Acanthopecten carboniferus (Stevens)
Euchondria neglecta Geinitz
Pecten (Entolium) aviculatus (Swallow)
Lima retifera Shumard
Allorisma terminale Hall
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Bucanopsis montfortiana Norwood and Pratten
Euomphalus catilloides Conrad

Phillipsia major Shumard.

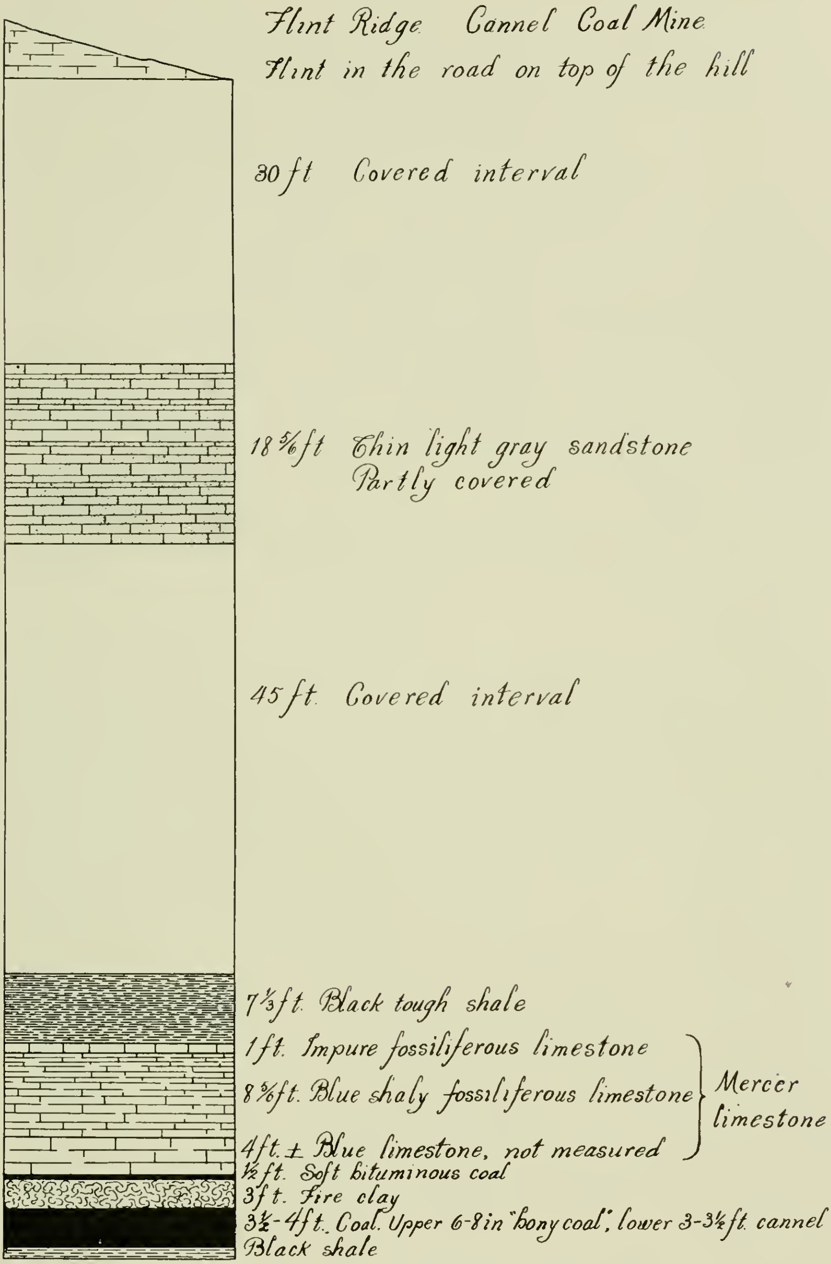
Flint Ridge Cannel Coal Mine
Flint in the road on top of the hill
30 ft Covered interval
18 5/6 ft Thin light gray sandstone
Partly covered
45 ft. Covered interval
7 1/3 ft. Black tough shale
1 ft. Impure fossiliferous limestone
8 5/6 ft. Blue shaly fossiliferous limestone
4 ft. ± Blue limestone, not measured
Mercer limestone
½ ft. Soft bituminous coal
3 ft. Fire clay
3½-4 ft. Coal. Upper 6-8 in "bony coal", lower 3-3½ ft. cannel
Black shale

FIG. 2. Section at the Flint Ridge Cannel Coal Mine.

A quarter of a mile south of Bald Knob where the highway crosses the hill at a slightly lower elevation, the Mercer limestone may be seen in the road, apparently in place. No fossils were collected here.

By the side of the road north of Bald Knob is a large block of Mercer limestone that has evidently slipped down from its original position. This had a thickness of two feet. The following fossils were collected from this block:

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus longispinus Sowerby
Spiriferina kentuckiensis (Shumard)
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Parallelodon tenuistriatus Meek and Worthen
Schizodus cuneatus Meek
Aviculopecten coxanus Meek and Worthen
Aviculopecten cf. *fasciculatus* Keyes
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Lima retifera Shumard
Allorisma terminale Hall
Pleurophorus subcostatus Meek and Worthen
Astartella newberryi Meek

FLINT RIDGE

In the southeastern part of Licking county and extending eastward into the western part of Muskingum is a well defined ridge with numerous spurs and outliers, which rises at its western extremity to an elevation of more than 1200 feet above sea level. Eastward its elevation is somewhat less, though it is still more than 1100 feet at the Licking-Muskingum county line; and for a distance of eight miles or more this ridge forms the dominant topographic feature of the region. The locality attracted the attention of the early settlers, and received its name, by reason of the extensive deposit of flint upon the highest parts of the hills.

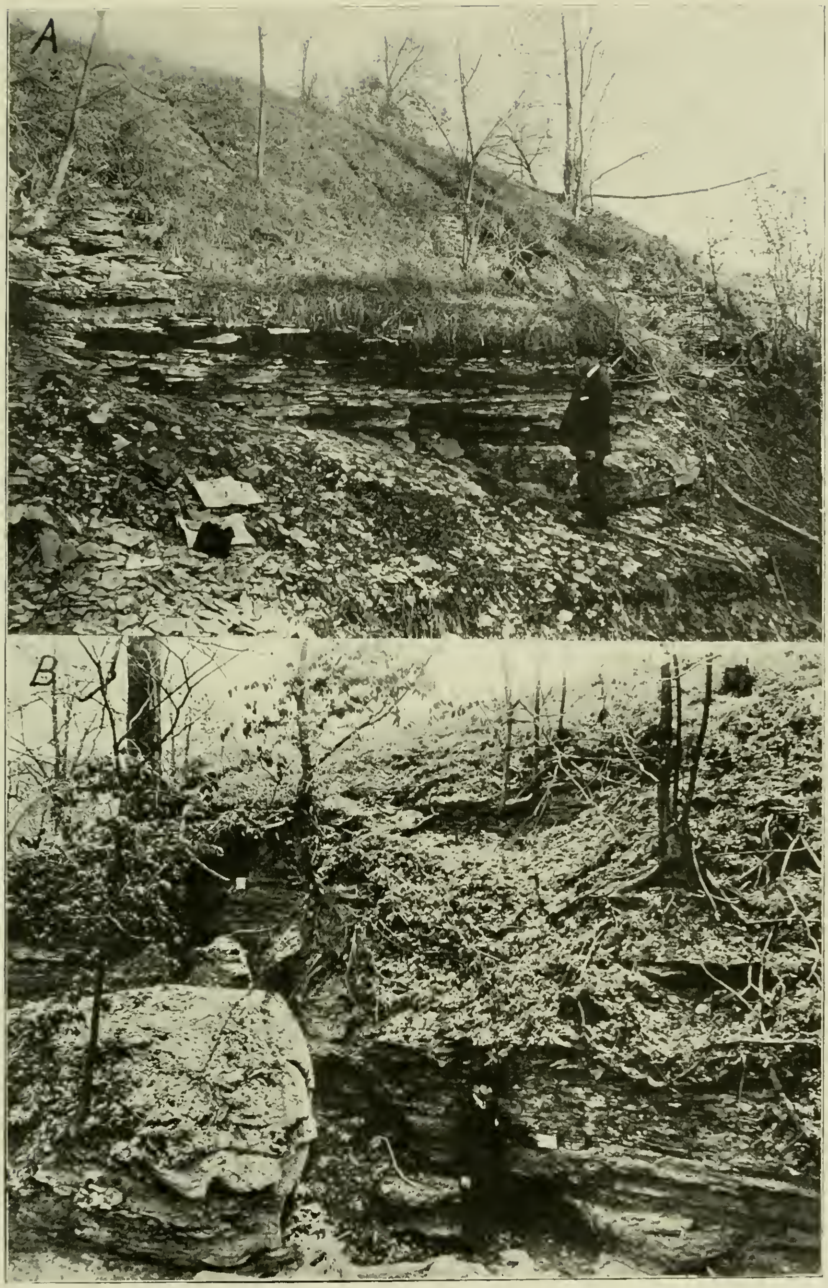

FIG. 3. *A*. Mercer limestone in Limestone Hollow, Flint Ridge, showing lower massive and middle shaly zone. *B*. Mercer limestone in Limestone Hollow, Flint Ridge, showing lower massive, middle shaly, and upper impure zones.

The flint is not seen in a continuous ledge or at a definite horizon on the hills, but is scattered over all the higher parts of the ridge in masses ranging in size from large blocks weighing many tons to the most minute fragments. This mantle of flint was aptly described in one of the early Ohio reports as lying "like a blanket" over the ridge. It is no doubt owing to this protecting mantle that the Flint Ridge region has been able to resist erosion better and to maintain a greater elevation than the surrounding country.

During the early part of the last century the flint was of considerable economic value to the inhabitants of this part of the state, as it furnished material from which they manufactured millstones or "buhrs." These millstones, while not considered equal to the best imported ones, still furnished an acceptable substitute for them at a time when importation was difficult, and many of the early mills of southeastern Ohio are said to have been supplied with millstones made of flint from Flint Ridge. This was not, however, the first use made of the flint. Numerous excavations along the summit of the ridge, made before the coming of white men into this region, give evidence that the flint was extensively worked by earlier inhabitants of the country, and the many flint darts and spear heads that have been picked up along the ridge and in the surrounding region indicate the principal use made of it. It is supposed that the Indians mined the flint, after first clearing away the protecting soil, by building on the surface of the solid flint large fires so that the underlying rock became very hot, and then throwing water on it, causing it to shatter. This process was repeated until blocks of fresh flint of a workable size could be obtained, the flint which had been protected by several feet of soil being much more easily worked than that which had been exposed to the weather for some time. There are said to be along the length of the ridge over eleven hundred of the pits left by this process of mining, the largest one being more than eighty feet in diameter and said to penetrate the Lower Mercer coal. Gerard Fowke, in his *Archaeological History of Ohio*, 1902, p. 624, says: "Evidently aboriginal excavations at Flint Ridge extended over a long period; for the material is found in the largest

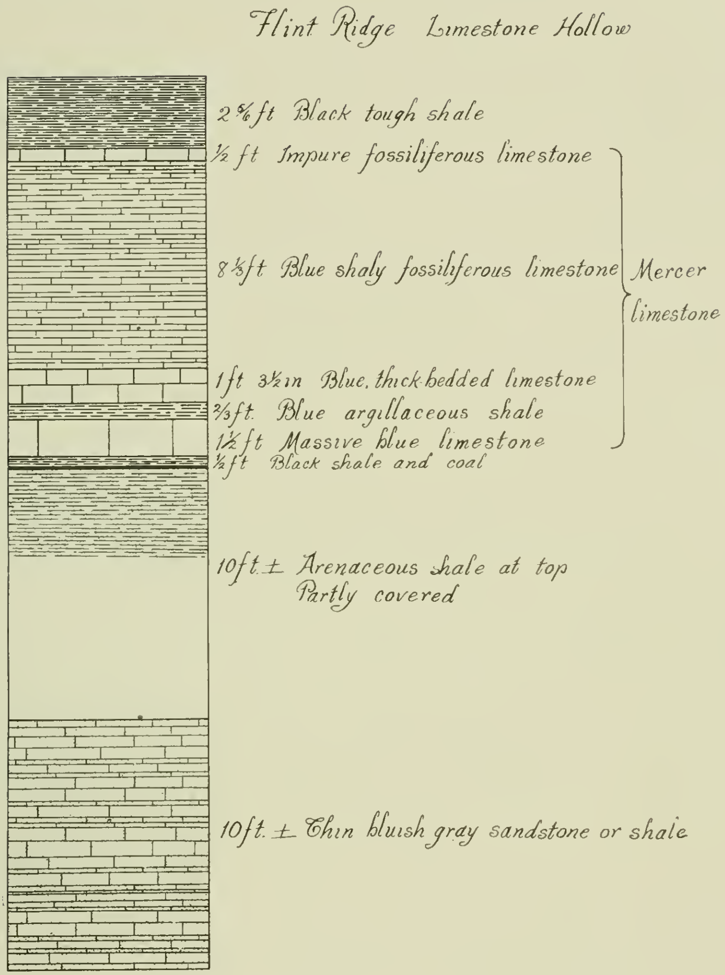
Flint Ridge Limestone Hollow
2⅚ ft Black tough shale
½ ft Impure fossiliferous limestone
8⅓ ft Blue shaly fossiliferous limestone
Mercer limestone
1 ft 3½ in Blue, thick-bedded limestone
⅔ ft. Blue argillaceous shale
1½ ft Massive blue limestone
½ ft Black shale and coal
10 ft. ± Arenaceous shale at top
Partly covered
10 ft. ± Thin bluish gray sandstone or shale

FIG. 4. Section in Limestone Hollow, Flint Ridge.

mounds explored in the Kanawha, Scioto and Miami valleys, as well as on the sites of modern villages."

In appearance the flint is quite attractive, fresh specimens being as a rule more or less translucent and exhibiting a range of colors varying from pure white through different shades of yellowish brown, red, purple, and blue, to black. When weathered it seems to become less translucent and often has a tendency to break up into small rectangular pieces. The flint contains numerous cavities which are usually lined, and sometimes completely filled, with druses of quartz crystals. Many of these crystals are large enough so that their crystalline form may be readily seen without the aid of a magnifier, while others are so small that they merely impart a frost-like appearance to the surfaces they cover. When carefully examined they appear to be almost colorless in themselves but they often borrow the color of the underlying flint and show beautiful shades of blue, amethyst, red, brown and yellow.

The more impure portions of the flint very frequently contain large numbers of small foraminifera of the species *Fusulina secalica*. In some places the rock is completely filled with these fossils, and as many as one hundred and fifty have been counted in a single square inch. The flint containing the *Fusulinas* is usually white or light buff in color, and does not show the more brilliant colors of the purer flint. The quartz crystals, however, are abundant, often being intermingled with the fossils. The flint of this character is said by Mr. Fowke to be found upon the borders of the flint area, while that which is purer, more compact and brighter colored occupies the central portion. On page 622 of the *Archeaological History of Ohio* he gives an account of the clearing out of one of the pits at Flint Ridge, in which was found forty inches of flint resting directly upon solid blue limestone.

It seems quite probable that the flint and underlying limestone represent the horizon of the Putnam Hill limestone, though more extensive field work will be necessary before such a correlation can be made with any degree of certainty.

Flint Ridge Cannel Coal Mine. Just north of the west end of Flint Ridge is a bed of cannel coal which has been mined in a small way for the last seventy years or more. At present coal is being

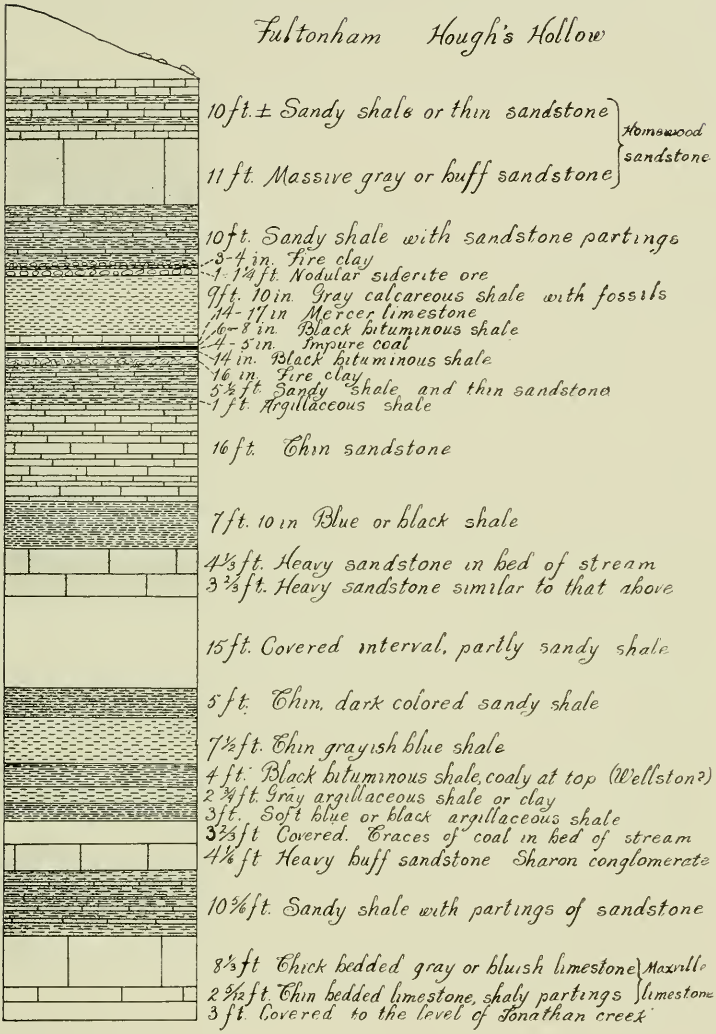
Fultonham Hough's Hollow
10 ft. ± Sandy shale or thin sandstone
11 ft. Massive gray or buff sandstone
Homewood sandstone
10 ft. Sandy shale with sandstone partings
3-4 in. Fire clay
1-1¼ ft. Nodular siderite ore
9 ft. 10 in. Gray calcareous shale with fossils
14-17 in. Mercer limestone
6-8 in. Black bituminous shale
4-5 in. Impure coal
14 in. Black bituminous shale
16 in. Fire clay
5½ ft. Sandy shale and thin sandstone
1 ft. Argillaceous shale
16 ft. Thin sandstone
7 ft. 10 in. Blue or black shale
4⅓ ft. Heavy sandstone in bed of stream
3⅔ ft. Heavy sandstone similar to that above
15 ft. Covered interval, partly sandy shale
5 ft. Thin, dark colored sandy shale
7½ ft. Thin grayish blue shale
4 ft. Black bituminous shale, coaly at top (Wellston?)
2¾ ft. Gray argillaceous shale or clay
3 ft. Soft blue or black argillaceous shale
3⅔ ft Covered. Traces of coal in bed of stream
4⅙ ft Heavy buff sandstone Sharon conglomerate
10⅚ ft. Sandy shale with partings of sandstone
8⅓ ft Thick bedded gray or bluish limestone
2 5/12 ft. Thin bedded limestone, shaly partings
Maxville limestone
3 ft. Covered to the level of Jonathan creek

FIG. 5. Section in Hough's Hollow, Fultonham.

taken from Mr. Wm. Jones' drift which is just north of the Flint Ridge road, and about one-quarter of a mile from the western boundary of Hopewell township. The following section was measured at this place, leveled from an old coal drift a few rods northwest of the Wm. Jones drift:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
13. Flint in the road at the west end of the ridge in the edge of the woods.		
12. Covered interval.	30	122½
11. Light gray to white coarse-grained, micaceous sandstone, friable and largely quartz. Partly covered.	18⅚	92½
10. Covered interval.	45	73⅔
9. Black tough shale, no fossils seen.	7⅓	28⅔
8. Top of *Mercer Limestone.* A layer of impure dark gray or bluish gray limestone containing many fossils, but the majority of them poorly preserved and fragmentary. When the rock is weathered the lime leaches out, leaving the rock buff or brown in color and much lighter in weight.	1	21⅓
7. Blue or bluish black limestone, fossils abundant and well preserved. In fresh exposures the limestone consists of massive layers with shaly partings. The upper layer of limestone is 1¾ feet thick. When weathered the limestone becomes shaly and is easily split up, and the fossils are readily obtained.	8⅚	20⅓
6. The lower part of the limestone and the underlying coal could not be measured at this drift, but there appears to be about four feet more of the limestone before the coal horizon is reached.	4±	11½
5. Soft coal, bituminous and with slickensides. Wm. Jones' coal drift.	½	7½
4. Fire clay containing a considerable amount of sand; heavy and hard on fresh exposure, but soon weathers soft and falls. In many places this shows slickensides.	3	7
3. "Bony" coal.	½±	4
2. Cannel coal with conchoidal fracture. This is said by one of the miners to thin toward the west to two feet and to thicken toward the east to six feet.	3–3½	3½
1. Black shale with *Lingula tighti* Herrick.		

A quantity of the limestone was taken out of this old drift two or three years ago in order to ascertain the exact horizon of the coal when the new entry was made, and from this material the following collection was made:

Fenestella shumardi Prout

Glossina waverlyensis Herrick
Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya radiata Meek and Worthen
Solenomya anodontoides Meek
Prothyris elegans Meek
Edmondia cf. *aspinwallensis* Meek
Edmondia ovata Meek and Worthen
Edmondia reflexa Meek
Nucula parva McChesney
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon obsoletus Meek
Avicula ohioense Herrick
Schizodus cuneatus Meek
Schizodus curtus Meek and Worthen
Schizodus wheeleri Swallow
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis Shumard
Aviculopecten herzeri Meek
Acanthopecten carboniferus Stevens
Pecten (*Entolium*) *aviculatus* (Swallow)

Entolium attenuatum Herrick
Lima retifera Shumard
Placunopsis carbonaria Meek and Worthen
Allorisma terminale Hall
Allorisma sp.
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Pleurophorus subcostatus Meek and Worthen
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Euphemus carbonarius (Cox)
Bucanopsis marcouana Geinitz
Bucanopsis montfortiana Norwood and Pratten
Pleurotomaria broadheadi White
Bulimorpha inornata Meek and Worthen
Soleniscus klipparti Meek

Conularia sp.

Orthoceras sp.
Nautilus sp.

Phillipsia major Shumard

At the four corners to the southeast of the coal drift is an exposure of sandstone supposed to be the Homewood, and a short distance from this, down the hill to the north the Mercer limestone is exposed in an old coal drift just below the highway. The section here is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
4. Flint in the road near the top of the hill east of the four corners.		
3. Covered interval.	42	132⅓
2. *Homewood sandstone.* Exposed in the gutter and at the side of the highway.	21	90⅓
1. Interval from the base of the Homewood sandstone as seen, to the base of the Mercer limestone.	69⅓	69⅓

The following fossils were collected from the Mercer limestone at this old coal drift:

Fenestella shumardi Prout

Orbiculoidea convexa (Shumard)
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Aviculopecten herzeri Meek
Acanthopecten carboniferus (Stevens)
Pecten (Entolium) aviculatus (Swallow)
Entolium attenuatum Herrick
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Bucanopsis marcouana Geinitz
Bucanopsis montfortiana Norwood and Pratten

Crinoid segments

Limestone Hollow. About three-quarters of a mile southeast of the cannel coal mine and just east of the road that leads south past the Fairview School, is a gully called Limestone Hollow where the entire thickness of the Mercer limestone may be seen. The section measured here is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
9. Black, rather tough shale which splits into rather thin laminae. Fossils scarce.	$2\frac{5}{6}$	$35\frac{2}{3}$
8. Top of *Mercer limestone.* One stratum of the impure limestone similar to that at the top of the Mercer at the cannel coal mine.	$\frac{1}{2}$	$32\frac{5}{6}$
7. Dark blue limestone which splits into rather shaly pieces with sharp edges; very fossiliferous, especially the upper part. Eight inches below the top is a very abundant *Productus cora* zone about one inch thick.	$8\frac{1}{3}$	$32\frac{1}{3}$
6. Blue, rather irregular, but fairly thick-bedded limestone.	$1\frac{1}{3}$	24
5. Bluish argillaceous shale.	$\frac{2}{3}$	$22\frac{2}{3}$
4. Massive blue limestone, not very fossiliferous. Base of *Mercer limestone.*	$1\frac{1}{2}$	22
3. Black shale and coal; only the top of the coal shown.	$\frac{1}{2}\pm$	$22\frac{1}{2}$
2. Partly covered. Bluish gray coarse arenaceous shales at top.	$10\pm$	20
1. Thin sandstones to arenaceous shales, bluish gray in color.	$10\pm$	10

The following species of fossils were obtained at this locality:

Fenestella shumardi Prout
Septopora biserialis Swallow

Glossina waverlyensis Herrick
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya anodontoides Meek
Edmondia reflexa Meek

Edmondia nebrascensis Geinitz
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Schizodus cuneatus Meek
Schizodus curtus Meek and Worthen
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten cf. *fasciculatus* Keyes
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Lima retifera Shumard
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Pleurophorus subcostatus Meek and Worthen
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Bellerophon crassus Meek and Worthen
Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Bucanopsis montfortiana Norwood and Pratten
Soleniscus klipparti Meek

Phillipsia trinucleata Herrick

Crinoid segments

Flint Ridge Four Corners. A little more than a mile east of the four corners near the coal drift another road from the north crosses the Flint Ridge road at what is known as Flint Ridge Four Corners. Just south of here on the road toward Brownsville a large block of flint may be seen at the side of the highway, and somewhat farther south the Mercer limestone is shown in the gutter. The following section was measured:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
8. Fairly pure, bluish white flint, showing some other colors, and with numerous cavities filled with quartz crystals.	5±	99½
7. Impure porous limestone weathering to a buff color, and containing many cavities filled with clay; somewhat shaly toward the bottom. The limestone contains some fossils, *Fusulina secalica*, *Chonetes mesolobus* N. & P., and *Reticularia perplexa* (McChesney).	3½+	94½
6. Calcareous shale.	1	91
5. Covered interval.	40	90
4. *Homewood sandstone.* Thin-bedded, bluish gray, micaceous sandstone, composed largely of quartz grains.	40	50
3. Thin black shale, no fossils seen.	4±	10
2. *Mercer limestone.* The deposit of limestone at this place is thinner than in the other exposures, but it presents the same lithological characters and carries the same fauna.	4½–5	6
1. Fire clay.	1±	1

About a quarter of a mile northeast of Flint Ridge Four Corners a ledge of flint is shown apparently in place at the head of a small gully. The flint on one side of the gully measured ten feet at its thickest place, while the greatest thickness of that on the other side was seven feet and three inches.

Buzzard Glory Knob. Two and one-half miles south of Flint Ridge, and just north of the National Pike west of Brownsville, is a high hill to which the name Buzzard Glory Knob is given on the topographic map, and which is locally called Benny Iden's Hill. The top of this hill is composed of an impure argillaceous limestone which lithologically resembles the limestone below the flint near the Flint Ridge Four Corners. There are a good many rather small blocks of flint scattered over the top of the hill, apparently the remnant of the flint limestone with which it was formerly capped. Specimens of *Fusulina secalica* are found in some of these blocks. The impure limestone contains a considerable number of fossils, and the following species were collected, *Chonetes mesolobus* being most abundant:

Fusulina secalica (Say)
Fenestella shumardi Prout
Septopora biserialis Swallow

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Productus punctatus (Martin)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Fairview Knob. This hill is a mile and a half from Buzzard Glory Knob, a little west of north, and the road from the Flint Ridge coal mine to the National Pike crosses the hill not far below its highest point. The hill is capped by the flint, and on its southern slope the Mercer limestone and several ledges of sandstone may be seen in the road. The following measurements were made:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
6. Flint ledge on the top of the hill.		
5. Interval to the top of the Mercer limestone shown along the highway. Immediately below the flint on the top of the hill is seen impure argillaceous limestone, the same as that observed on Buzzard Glory Knob. Farther down the hill some blocks of sandstone are shown in the road near its highest point. These are not well shown, but they are evidently Homewood sandstone.	76	214
4. *Mercer limestone.*	8	138
3. Interval to ledge of coarse-grained sandstone in the road.	10	130
2. Interval to ledge of coarse-grained sandstone.	60	120
1. Interval to lowest ledge of sandstone in the road. This is coarse-grained quartz sandstone, probably the Sharon.	60	60

North of this hill 13 feet of the Mercer limestone is shown along the highway, its base being about 110 feet below the flint on top of the hill. A coal drift in the field to the west is apparently at the same level as the base of the Mercer.

The top of Fairview Knob is fairly well covered with masses of flint, but the underlying impure limestone was found in woodchuck burrows almost to the top, which indicates that only the lower part of the flint is left. This impure limestone contains numerous irregular cavities out of which clay-like masses have weathered. In the blocks not weathered so much the clay fillings were found. The limestone contains the same fossils as those collected on Buzzard Glory Knob.

The Logan Stevens Farm. On this farm, a mile and a half west of Fairview Knob, a well was drilled for oil in the summer of 1908. A large amount of the flint is shown in the road on the ridge just east of this well, and in the lane near Mr. Stevens' house the Homewood sandstone is exposed. According to the barometer this exposure of Homewood sandstone is 45 feet below the flint on top of the ridge, and the derrick floor at the oil well is 110 feet lower than the sandstone. The Mercer limestone on the Flint Ridge road to the north is 75 feet higher than the derrick floor, or 35 feet lower than the sandstone. The following record was obtained from one of the well drillers:

	Feet
8-inch drive pipe	119
Berea Grit sand, top	850
Berea Grit sand, bottom	865
$6\frac{5}{8}$-inch casing	870
Niagara Lime, top	1820
Heavy flow of water at 2500 feet, hole filled up 1800 feet.	
Niagara Lime, bottom	2720
$5\frac{3}{16}$-inch casing	2720
Clinton Sand, top	2888
Light show of oil.	
Clinton Sand, bottom	2932
Total depth	2971

The "Niagara Lime" of this record no doubt includes the Devonian and Monroe limestones as well.

FULTONHAM

Hough's Hollow. At Fultonham in the southwestern corner of Muskingum county there are numerous exposures of the Mercer limestone, which is well shown here in its relation to the underlying rocks. Several of these exposures were studied and sections measured, the first one being in Hough's Hollow, a ravine directly north of the village.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
30. The upper one hundred feet or so of the hills is covered, but toward the base of this covered portion rather large broken blocks of coarse sandstone are scattered over the hillside. These blocks are weathered black on the outside, but fresh fractures show a rather dark brown color. Fragments of Lepidodendron are commonly found.	100±	$255\frac{5}{12}$
29. *Homewood sandstone.* Gray or buff sandy shales or thin micaceous sandstone.	10±	$155\frac{5}{12}$
28. Massive gray or buff sandstone composed mostly of quartz grains. Base of *Homewood sandstone.*	11	$145\frac{5}{12}$
27. Light colored arenaceous shale with sandstone partings. The sandstone layers are closer and heavier toward the top and are similar in appearance to the massive sandstone above. At the base of the shale is an horizon of ore nodules.	10	$134\frac{5}{12}$
26. Fire clay.	$\frac{1}{3}$	$124\frac{5}{12}$
25. Siderite ore, nodular.	$1\text{–}1\frac{1}{4}$	$124\frac{1}{12}$
24. Dark gray calcareous shale with fossils.	$9\frac{5}{6}$	$122\frac{5}{6}$
23. *Mercer limestone.* Heavy dark blue limestone varying from 14 inches thick in one layer to 17 inches thick in two layers only fifteen feet away. The lower surface is somewhat irregular, and the limestone is fossiliferous, containing crinoid segments and brachiopod shells. The limestone does not become shaly on weathering as does that at Bald Knob and Flint Ridge, but breaks out in large rectangular blocks which retain their shape and are conspicuous in the bed of the stream for some distance below the horizon of the limestone.	$1\frac{1}{6}\text{–}1\frac{5}{12}$	113
22. Black bituminous shale.	$\frac{1}{2}\text{–}\frac{2}{3}$	$111\frac{7}{12}$
21. Rather impure, blocky coal.	$\frac{1}{3}\text{–}\frac{5}{12}$	$110\frac{11}{12}$
20. Thin black bituminous shale.	$1\frac{1}{6}$	$110\frac{1}{2}$

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
19. Fire clay.	$1\frac{1}{3}$	$109\frac{1}{3}$
18. Sandy shale and thin sandstone, showing some cross bedding at the base, light gray, buff or bluish.	$5\frac{1}{2}$	108
17. Argillaceous shale with some sand, light gray in color.	1	$102\frac{1}{2}$
16. Heavy sandy shale and thin sandstone, light gray, buff or bluish.	16	$101\frac{1}{2}$
15. Thin bedded dark blue or black shale.	$7\frac{5}{6}$	$85\frac{1}{2}$
14. Heavy bedded sandstone in the bed of the stream, buff in color on fresh surface, but weathers brown.	$4\frac{1}{3}$	$77\frac{2}{3}$
13. Heavy sandstone similar to that above.	$3\frac{2}{3}$	$73\frac{1}{3}$
12. Covered, partly sandy shale	15	$69\frac{2}{3}$
11. Thin, dark colored sandy shale weathering into small irregular pieces.	5	$54\frac{2}{3}$
10. Thin light gray or blue shale weathering into small rectangular pieces.	$7\frac{1}{2}$	$49\frac{2}{3}$
9. Black bituminous shale, coaly in some places, especially toward the top, and with blocky sandstone layers two or three inches thick. (Wellston coal horizon?)	4	$42\frac{1}{6}$
8. Light gray argillaceous shale, weathering to light gray or yellowish clay.	$2\frac{3}{4}$	$38\frac{1}{6}$
7. Soft argillaceous shale, dark blue or almost black.	3	$35\frac{5}{12}$
6. Covered interval. Traces of coal in the bed of the stream. (Sharon coal?)	$3\frac{2}{3}$	$32\frac{5}{12}$
5. *Sharon conglomerate.* Thick bedded, buff, coarse-grained quartz sandstone.	$4\frac{1}{6}$	$28\frac{3}{4}$
4. Dark blue sandy shale weathering brown, with partings and lenses of light buff or brownish sandstone.	$10\frac{5}{6}$	$24\frac{7}{12}$
3. *Maxville limestone.* Thick bedded gray or bluish limestone with some fossils. The heaviest bed, which is at the base, is about two feet in thickness.	$8\frac{1}{3}$	$13\frac{3}{4}$
2. Thin bedded blue limestone with shaly partings, quite fossiliferous.	$2\frac{5}{12}$	$5\frac{5}{12}$
1. Covered to the level of Jonathan creek.	3	3

Fossils collected from the Mercer limestone in Hough's Hollow:

Orthothetes crassus (Meek and Hayden)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spirifer camaratus Morton
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Fossils collected from the gray calcareous shale which lies just above the Mercer limestone:

Lophophyllum profundum (Milne-Edwards and Haime)
Glossina waverlyensis Herrick
Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Dielasma cf. *turgidum* (Hall)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Edmondia ovata Meek and Worthen
Edmondia nebrascensis Geinitz
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsolctus Meek
Aviculopinna americana Meek
Myalina swallovi McChesney
Aviculopecten coxanus Meek and Worthen
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Allorisma sp.
Pleurophorus oblongus Meek
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Dentalium sublaeve Hall

Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Euphemus nodocarinatus Hall
Bucanopsis montfortiana Norwood and Pratten
Pleurotomaria sp.

Orthoceras sp.

Crinoid segments and plates.

Stonehouse Hollow. Another section was taken in Stonehouse Hollow, on the opposite side of Jonathan creek and a mile northwest of Hough's Hollow, where the highway crosses the creek.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
26. *Homewood sandstone.* Thin bedded, gray, micaceous sandstone and shale.	10±	147⅚
25. Massive, coarse-grained buff or gray quartz sandstone. On the east side of the ravine a 12-foot ledge of this sandstone is shown with traces of coal and fire clay at the base (Tionesta coal?). About six feet from the base of this ledge is a fossil trunk of a tree 14 feet long. Base of *Homewood sandstone.*	12	137⅚
24. Thin light colored micaceous sandy shales, rather coarse.	4	125⅚
23. Iron ore horizon. One large nodule fallen from the bank measured two feet long, one foot wide, and one foot thick.	½±	121⅚
22. Thin gray calcareous shale with fossils.	12	121⅓
21. *Mercer limestone,* with iron ore at the top.	2	109⅓
20. Bituminous black shale with a four-inch layer of coal about the middle.	1	107⅓
19. Light gray fire clay.	3	106⅓
18. Thin gray sandy shale.	6	103⅓
17. Covered interval.	19⅚	97⅓
16. Heavy, compact fine grained sandstone, very light gray on fresh fracture, weathers buff or dark brown; shown on side of ravine. (Upper Massillon sandstone?)	2⅔	77½
15. Covered interval.	3½	74⅚

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
14. Thin bedded shale, black at the base but changing to light buff or gray at the top and becoming more sandy.	28⅓	71⅓
13. Thin black shale with numerous horizons of ore nodules, the most distinct being a two-inch layer six inches from the base, and a one-half to one inch layer ten inches from the base.	9	43
12. Black bituminous shale.	5/12	34
11. Impure coal. (Wellston coal?).	1/12	33 7/12
10. Black bituminous shale.	⅙	33½
9. Light gray argillaceous shale, brownish when weathered; with some lenses of coal toward the top.	4½	33⅓
8. Heavy, cross-bedded, gray or buff sandstone, weathering brown. (Lower Massillon?).	4⅔	28⅚
7. Thin shale, black at the base, light gray at the top.	11⅚	24⅙
6. Black shale with nodules of iron ore.	½	12⅓
5. Thin black shale.	2	11⅚
4. Black shale with nodules of iron ore.	½	9⅚
3. Impure blocky coal with shaly partings in the lower part. (Sharon coal?)	1⅓	9⅓
2. Black bituminous shale.	1	8
1. Covered interval, to Maxville limestone in the bed of the stream near the railroad bridge.	7	7

Wortman's Ravine. On the south side of Jonathan creek directly opposite Stonehouse Hollow is another ravine where the Mercer limestone is exposed. In this ravine the interval between the Homewood sandstone and the Mercer limestone is much reduced, not exceeding 8 feet, and in one place being only one foot.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
11. *Homewood sandstone.* Coarse grained gray or buff sandstone, fairly thin bedded.	15	89 7/12
10. Massive gray or buff sandstone composed mostly of quartz grains. The lower part is very irregular and shows somewhat cross-bedded structure where it cuts out the shale below.	10–17	74 7/12
9. Dark gray calcareous shale with fossils. The thickness of the shale varies on account of its being cut out by a "horseback" of the overlying sandstone.	1–8	64 7/12

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
8. *Mercer limestone.* Heavy dark blue very hard limestone with some fossils which are obtained with difficulty, *Productus longispinus*, *Productus semireticulatus*, *Reticularia perplexa*, and crinoid segments.	1	$56\frac{7}{12}$
7. Black, somewhat shaly, rather soft limestone, very fossiliferous, but the fossils crushed and poorly preserved. *Seminula argentea*, *Productus longispinus*, *Productus nebraskensis*, *Chonetes mesolobus*, *Orthothetes crassus*, and *Astartella varica* were identified.	$\frac{2}{3}$	$55\frac{7}{12}$
6. Impure coal.	$\frac{1}{2}$	$54\frac{11}{12}$
5. Light gray sandy fire clay containing Stigmaria.	$\frac{5}{6}$	$54\frac{5}{12}$
4. Impure coal, hard and blocky.	$\frac{1}{4}$	$53\frac{7}{12}$
3. Fire clay similar to that above the coal.	1	$53\frac{1}{3}$
2. Gray sandy shale or thin sandstone with Stigmaria toward the top.	$16\frac{2}{3}$	$52\frac{1}{2}$
1. Thin black dark gray or blue arenaceous shale with black impressions resembling Stigmaria. Covered to the level of Jonathan creek, and not measured.	$35\frac{2}{3}$	$35\frac{2}{3}$

The Roberts' Ravine. In a ravine on the land of Harrison Roberts about half way between Wortman's Ravine and the village of Fultonham the Mercer limestone and the Homewood sandstone are exposed. The interval between them was not measured, but it is not more than eight or ten feet and consists entirely of the dark gray calcareous shale that is seen above the Mercer limestone in the other ravines studied.

From the Mercer limestone in this ravine the following species were collected:

Productus semireticulatus (Martin)
Productus longispinus Sowerby
Spirifer camaratus Morton
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Crinoid segments

The following fossils were obtained in the calcareous shale:

Lophophyllum profundum (Milne-Edwards and Haime)

Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus cora d'Orbigny
Productus longispinus Sowerby
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Seminula argentea (Shepard)

Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon tenuistriatus Meek and Worthen
Schizodus curtus Meek and Worthen
Aviculopecten coxanus Meek and Worthen
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Allorisma sp.
Pleurophorus oblongus Meek
Cypricardinia carbonaria Meek
Astartella newberryi Meek
Astartella varica McChesney

Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Euphemus nodocarinatus Hall
Bucanopsis montfortiana Norwood and Pratten

Crinoid segments and plates.

The Allen Coal Entry. At the west end of Fultonham an entry has been made to Coal No. 5 on the land of Mr. Allen just north of the Zanesville and Maysville pike. Farther down the hill and across the road from the coal entry the Mercer limestone is exposed on a small branch of Bush creek. The limestone is here 2 feet and 8 inches thick with a layer of iron ore nodules on top 6 inches thick. Below the limestone coal and fire clay may be seen similar to that in Hough's Hollow. The iron ore on the top of the limestone gives it a very irregular surface when weathered. The interval from the limestone to Coal No. 5 is 85 feet and is covered with the exception of two or three feet immediately above the limestone and ore, where the dark gray fossiliferous shale is exposed. This coal mine is not worked at present, but one-quarter to one-third of a mile farther west on the land of Mr. Hartness the same seam is worked in two mines. The thickness of the coal at these mines is given by the workmen as 4 feet and 8 inches, and the coal is of excellent quality. The workmen at these mines state that there is another vein of coal not far below No. 5, but not of workable thickness. The roof of the coal consists of soft sandy shale which in some parts of the mines has caved badly, causing depressions of considerable size on the hill above the entries. In one of these about 15 feet of the shale is shown in place above the coal.

Just back of the old toll house on the Zanesville and Maysville pike and not far from the exposure of the Mercer limestone where measured, a second limestone 8 to 10 inches thick was formerly exposed about 20 feet below the Mercer, but this lower limestone is now covered.

The following species of fossils were collected from the Mercer limestone below the Allen coal entry and on the adjoining land of Mr. Wm. Axline, where the limestone is shown in several places:

Rhombopora lepidodendroides Meek

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Dentalium sublaeve Hall

Bellerophon crassus Meek and Worthen
Pleurotomaria sp.
Loxonema cerithiforme Meek and Worthen
Soleniscus fusiformis Hall
Soleniscus klipparti Meek

Phillipsia trinucleata Herrick
Crinoid segments and plates.

East Fultonham. In the hill behind the plant of the Fultonham Brick Company the Mercer limestone and underlying rocks are exposed in a cliff about sixty-five feet high. This exposure is the farthest east of any studied in this region, and is located near the Fultonham station on Jonathan creek.

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
11. Surface clay.		
10. *Mercer limestone.* Massive dark blue limestone which weathers lighter in color but does not become shaly to any extent; contains crinoid segments and brachiopod shells.	1½ ±	64¼
9. Coal.	¼	62¾
8. Fire clay with iron concretions.	8	62½
7. White micaceous sandstone containing a little fire clay.	4½	54½
6. Hard gray sandstone, rather thin bedded.	2⅛	50
5. Heavy micaceous sandstone, rather fine grained, buff or gray, which contains some iron concretions especially in the lower part, and is often iron stained. The workmen at the brick yard say this sandstone weathers to "bastard fire clay."	3½	47½
4. Shale and fire clay, upper part light colored, lower part darker, with numerous ore nodules.	12	44
3. Sandy light colored fire clay, sometimes replaced by hard bluish limestone, the upper 8 or 10 inches with abundant nodules of iron ore.	2	32
2. Blue shale.	18	30
1. Fire clay. Covered to the Maxville limestone in the banks of Jonathan creek; not measured.	12	12

The following fossils were collected from the Mercer limestone at the top of this section:

Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Zeocrinus sp.
Crinoid segments.

The Mercer limestone in the Fultonham region consists usually of a single hard compact layer of a dark blue color. In one or two places it is divided into two layers, but these are in contact without shale or other material separating them. A layer of iron ore is often found lying immediately upon the top of the limestone, which upon weathering gives it a very irregular upper surface. The limestone does not weather shaly as it does in the Bald Hill and Flint Ridge regions, but breaks out in large rectangular blocks which retain their shape when weathered. In the older valleys and along the hillsides where the other members of the Pottsville and Allegheny formations have been covered with soil and vegetation the limestone blocks are often quite conspicuous and mark the horizon of the Mercer. This is particularly true in the open fields to the south and west of the village, and along Bush creek toward Somerset. It is a noticeable fact that, whereas in the gullies formed by the younger streams the Homewood sandstone is the conspicuous member exposed, often forming cliffs along the valley walls while the lower members of the Pottsville formation and those of the Allegheny formation above are frequently covered with soil, in the older valleys the Mercer limestone is the member left exposed after all the others are covered.

The fauna of the limestone in this region differs somewhat from that of the exposures at Bald Knob and Flint Ridge, the principal difference being in the almost complete absence of the small pelecypods so abundant in those localities. The gray calcareous shale overlying the limestone, however, carries the same pelecypod fauna as the shaly limestone farther northwest. The one pelecypod obtained from the limestone in this vicinity was collected at the section studied farthest northwest, where the lower part of the limestone is somewhat shaly and softer than in any of the other exposures. The most conspicuous fossils in the limestone about Fultonham are the large crinoid segments with pentamerous centers. The organic part of the segments has been replaced by calcite, which presents quite a contrast to the dark blue limestone surrounding the segments and filling the centers. Crinoid stems several inches long are not uncommon, and occasionally one is found as much as two feet in length.

SOMERSET

Southwest from Fultonham the Mercer limestone shows a tendency to become thicker, and in the cut along the Baltimore and Ohio Railroad south of Somerset it is exposed with a thickness of 4 feet and 8 inches. The limestone here is in one massive layer with the upper part flinty in places, and is dark blue or almost black in color. The lower part of the limestone is very fossiliferous, showing a great variety of species. In general appearance the limestone is not unlike that at Fultonham; but it breaks much more easily and weathers somewhat shaly, in these respects, as well as in fossil contents, more closely resembling the limestone at Bald Knob and Flint Ridge.

Above the limestone a few fragments of very thin brittle black shale were found, which contained very small gasteropod shells. Below the limestone is a layer of black bituminous shale which is more coaly toward the top; and below this is a fire clay.

The following collection of fossils was made from the limestone:

Fenestella shumardi Prout
Septopora biserialis Swallow
Prismopora sereata Meek
Orbiculoidea convexa (Shumard)
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten

Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Rhipidomella pecosi (Marcou)
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya radiata Meek and Worthen
Solenomya anodontoides Meek
Edmondia nebrascensis Geinitz
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Schizodus wheeleri Swallow
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten herzeri Meek
Acanthopecten carboniferus (Stevens)
Pecten (*Entolium*) *aviculatus* (Swallow)
Entolium attenuatum Herrick
Lima retifera Shumard
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek

Cypricardinia carbonaria Meek
Astartella newberryi Meek
Astartella varica McChesney

Dentalium sublaeve Hall
Euomphalus sp.
Conularia sp.
Crinoid segments.

ELIZABETH

At Elizabeth, a station on the Zanesville and Western Railroad between Fultonham and Zanesville, the Homewood sandstone and underlying shale are exposed in a cliff along Jonathan creek, by the dam just above the highway bridge. The cliff was not measured, but there appears to be about 20 feet of the Homewood sandstone, which here shows an irregular lower surface similar to that in Wortman's Ravine near Fultonham. Just above the bridge a very thin seam of coal is shown at the base of the sandstone. Below the sandstone are 30 feet or more of black to gray shales; and blocks of what is apparently Mercer limestone are visible in the bed of the stream at the bridge. From Elizabeth to Zanesville along the line of the Zanesville and Western Railroad, frequent exposures of the Homewood are seen, many of them showing in the lower part the cross-bedding and other irregularities that indicate disconformity.

ZANESVILLE

Putnam Hill. At the base of Putnam Hill in Zanesville the Mercer limestone appears in the bed of the Muskingum river, the Upper Mercer limestone a short distance above water level, and the Putnam Hill limestone farther up the hill at the side of the road on the dugway. The section from river level to the upper limestone is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
16. Gray shale above Putnam Hill limestone.	25	$116\frac{11}{12}$
15. *Putnam Hill limestone.* Type locality. Heavy bluish gray limestone.	$3\frac{11}{12}$	$91\frac{11}{12}$
14. Black fossiliferous shale.	$\frac{1}{6}$–$2\frac{1}{6}$	88
13. Coal (Clarion?).	$\frac{3}{4}$	$85\frac{5}{6}$
12. Fire clay, Putnam Hill. This is gray or yellowish and not of the best grade.	$3\frac{2}{3}$	$85\frac{1}{12}$
11. Black or sometimes bluish shale.	$4\frac{5}{12}$	$81\frac{5}{12}$
10. Impure coal and shale (Brookville?).	1	77
9. Gray shale or clay to the level of the road. All the rocks exposed above the level of the road belong in the Allegheny formation.	$4\frac{3}{4}$	76
8. Covered interval.	42	$71\frac{1}{4}$
7. Mainly arenaceous shale, grayish in color.	$3\frac{1}{6}$	$29\frac{1}{4}$
6. Bluish argillaceous shale.	4	$25\frac{3}{4}$

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
5. *Homewood sandstone.* Heavy, buff, coarse-grained sandstone, rather soft and micaceous. A few rods farther south this sandstone is much thicker and shows disconformity associated with cross-bedding, folding and faulting in the lower part.	$3\frac{2}{3}$	$21\frac{3}{4}$
4. Gray arenaceous shale. About $1\frac{1}{2}$ or 2 feet below the sandstone is a concretionary layer in the shale.	$4\frac{1}{3}$	$18\frac{1}{12}$
3. Bluish-black shales which are very thin and break into very small pieces.	$8\frac{5}{12}$	$13\frac{3}{4}$
2. *Upper Mercer limestone,* with limonite ore. There are four layers of the limestone shown, the upper one 6 to 8 inches thick and containing iron ore, the next a 5-inch layer without a conspicuous amount of ore, a 5-inch layer with iron ore, and the lowest a 10-inch layer without the ore. The limestone is dark gray, weathering almost black except where the iron ore gives it a dark red or brown color. Fossils appear to be very scarce.	$2\frac{1}{3}$	$5\frac{1}{3}$
1. Covered to water level. All of the lower part of the section, from the road on the dugway to river level belongs in the Pottsville formation.	3	3

The Weller Pottery. In the cliff behind the Weller Pottery, which is located on the north side of the Zanesville and Western Railroad not far from the Putnam station, an excellent exposure of the Homewood sandstone is shown. The section is as follows:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
4. Alternating shales and sandstones, some of the shales being very fossiliferous, with remains of trees, etc.	$22\frac{1}{6}$	$53\frac{1}{3}$
3. Brookville coal.	$1\frac{5}{6}$	$31\frac{1}{6}$
2. Dark, almost black, shale or fire clay.	$1\frac{5}{6}$	$29\frac{1}{3}$
1. *Homewood sandstone.* Top of the Pottsville formation. The sandstone is very thick and massive, some of the layers being 10 feet thick. It is coarse and micaceous, and is a dark steel-gray in color, sometimes iron-stained. Below the floor of the quarry 20 feet more of Homewood sandstone are said to be buried.	$27\frac{1}{2}$	$27\frac{1}{2}$

ROSEVILLE

The Mercer limestone is apparently below drainage level at Roseville, and the Putnam Hill limestone is exposed 47 feet above the level of the south branch of Moxahala creek at the brick yard just north of the town. The following section was measured in the lower part of this hill:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
8. Shale and sandstone.	10±	$81\frac{5}{6}$
7. Lenticular or nodular layer of sandstone, gray with brown streaks when weathered; shows cross-bedded structure.	1-2	$71\frac{5}{6}$
6. Blue clay shale with some sand (makes "vitreous" brick).	20±	$69\frac{5}{6}$
5. *Putnam Hill limestone.* A single layer of gray or bluish gray crystalline limestone which weathers brown or buff. The upper 4 inches is not very fossiliferous, but the lower part is quite fossiliferous, the fossils weathering out in relief. The limestone contains many crinoid segments, and is very hard and massive.	$2\frac{1}{6}$	$49\frac{5}{6}$
4. Coal.	$\frac{1}{3}$	$47\frac{1}{3}$
3. Fire clay.	3	47
2. Massive sandstone, buff streaked with brown when weathered.	5	44
1. Covered to water level.	39	39

The following fossils were found in the Putnam Hill limestone at this locality:

Productus semireticulatus (Martin)
Productus cora d'Orbigny
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney) (small, numerous)

Bellerophon carbonarius (Cox) ?

Small crinoid segments.

On the land of Mr. Ryland in the northern part of Roseville the Putnam Hill limestone was formerly quarried to some extent and used in the manufacture of lime which is said to have been dark colored, but strong and of good quality.

A mile and a half west of Roseville, on Eel Run an oil well has recently been drilled on the land of David Allen, of which the following record was obtained:

	THICKNESS	TOTAL THICKNESS
	Feet	*Feet*
10 inch pipe	40	40
Clay and slate	70	110
Lime and iron	35	145
Slate and shale	250	395
Salt sand and slate	155	550
8-inch casing	...	550
Slate and shale	350	900
Berea sand	10	910
Red rock	10	920
6½-inch casing	....	920
Brown shale	450	1370
Cinnamon	150	1520
Slate and shale	450	1970
Big cinnamon	250	2220
Slate	90	2310
Brown shells and iron	15	2325
Top of lime	....	2325
Bottom of lime	....	3280
Top of sand	....	3432
Bottom of sand	....	3476
Total depth	....	3479
Water at 3050		

The 955 feet of limestone in this record evidently includes the Devonian, Monroe and Niagara limestones. The figures for this well, as compared with those for the well at Flint Ridge, are as follows:

	ROSEVILLE	FLINT RIDGE
From derrick floor to Berea Grit	900	850
Berea Grit	10	15
From Berea Grit to limestones	1415	955
Devonian, Monroe & Niagara limestones	955	900
From limestones to Clinton sand	152	168
Clinton sand	44	44

It will be observed that the greatest variation is in the interval between the Berea grit and the top of the limestone. This place in the geological scale is occupied by the Bedford and Ohio shales. The difference of the thickness of these shales at Flint Ridge and Roseville is 460 feet, and as the two wells are approximately 17 miles apart, this would mean an average increase of 27 feet per mile in the thickness of the shales, from northwest to southeast. This agrees closely with Dr. Bownocker's statement in regard to the thickening of these formations toward the east, in his bulletin on oil and gas (*Geological Survey of Ohio*, Fourth Series, Bulletin No. 1, 1903, p. 119).

SUMMARY

The exposures of the Mercer limestone at Bald Knob and Flint Ridge show the same lithological character and carry the same fauna. The thickness at Bald Knob could not be measured, but at Flint Ridge the greatest thickness is about 14 feet, and the limestone is underlain by cannel coal of workable thickness. The greater part of the limestone is shaly and fossiliferous, but there is a layer of impure, very fossiliferous limestone at the top and a somewhat thicker part of heavy, only moderately fossiliferous limestone at the bottom. The fossils are mostly brachiopods and small pelecypods, the number of species of pelecypods being two or three times as great as the number of species of brachiopods.

In the Fultonham region the greatest thickness of the Mercer limestone is a little less than 3 feet, and it consists of a single massive layer that does not become shaly on weathering. The underlying coal is not more than 6 inches thick. Above the limestone is a gray calcareous shale in which are found many of the pelecypods and other fossils of the Flint Ridge region. The limestone itself carries principally a brachiopod and gasteropod fauna, only one pelecypod being found. The interval from the base of the Sharon conglomerate to the Mercer limestone is much less than at Bald Knob, and the whole section seems to be shortened.

At Somerset the limestone is a little less than 5 feet thick, and its general appearance when in place is similar to that of the Mercer limestone at Fultonham, though it is more nearly black and contains some flint. When weathered it becomes shaly, and more closely resembles the limestone at Flint Ridge and Bald Knob; and it contains the same fossils as the limestone at those localities.

The entire list of fossils collected from the Mercer limestone at all of the exposures studied is as follows:

Lophophyllum profundum (Milne-Edwards and Haime)

Fenestella shumardi Prout
Septopora rectistyla Whitfield
Septopora biserialis Swallow
Prismopora sereata Meek
Rhombopora lepidodendroides Meek

Glossina waverlyensis Herrick
Orbiculoidea convexa (Shumard)
Orbiculoidea missouriensis Shumard
Orthothetes crassus (Meek and Hayden)
Chonetes mesolobus Norwood and Pratten
Productus semireticulatus (Martin)
Productus cora d'Orbigny
Productus longispinus Sowerby
Productus nebraskensis Owen
Rhipidomella pecosi (Marcou)
Dielasma cf. *turgidum* (Hall)
Spiriferina kentuckiensis (Shumard)
Spirifer camaratus Morton
Spirifer rockymontanus Marcou
Reticularia perplexa (McChesney)
Seminula argentea (Shepard)

Solenomya radiata Meek and Worthen
Solenomya anodontoides Meek
Prothyris elegans Meek
Edmondia cf. *aspinwallensis* Meek
Edmondia ovata Meek and Worthen
Edmondia reflexa Meek
Edmondia nebrascensis Geinitz

Nucula beyrichi von Schauroth
Nucula parva McChesney
Leda bellistriata Stevens
Yoldia stevensoni Meek
Parallelodon carbonarius Cox
Parallelodon tenuistriatus Meek and Worthen
Parallelodon obsoletus Meek
Parallelodon sangamonensis
Aviculopinna americana Meek
Avicula ohioense Herrick
Myalina swallovi McChesney
Schizodus cuneatus Meek
Schizodus curtus Meek and Worthen
Schizodus wheeleri Swallow
Aviculopecten coxanus Meek and Worthen
Aviculopecten occidentalis (Shumard)
Aviculopecten herzeri Meek
Aviculopecten cf. *fasciculatus* Keyes
Acanthopecten carboniferus (Stevens)
Euchondria neglecta Geinitz
Pecten (*Entolium*) *aviculatus* (Swallow)
Entolium attenuatum Herrick
Lima retifera Shumard
Placunopsis carbonaria Meek and Worthen
Allorisma terminale Hall
Allorisma sp.
Pleurophorus tropidophorus Meek
Pleurophorus oblongus Meek
Pleurophorus subcostatus Meek and Worthen
Cypricardinia carbonaria Meek
Astartella vera Hall
Astartella newberryi Meek
Astartella varica McChesney

Dentalium sublaeve Hall

Bellerophon crassus Meek and Worthen
Bellerophon percarinatus Conrad
Euphemus carbonarius (Cox)
Euphemus nodocarinatus Hall

Bucanopsis marcouana Geinitz
Bucanopsis montfortiana Norwood and Pratten
Pleurotomaria broadheadi White.
Pleurotomaria sp.
Euomphalus catilloides Conrad
Euomphalus sp.
Loxonema cerithiforme Meek and Worthen
Bulimorpha inornata Meek and Worthen
Soleniscus fusiformis Hall
Soleniscus klipparti Meek

Conularia sp.

Nautilus sp.
Orthoceras sp.

Phillipsia major Shumard
Phillipsia trinucleata Herrick

Zeocrinus sp.
Crinoid segments and plates.

In the naming and arrangement of these fossils Dr. A. W. Grabau's Index Fossils and Stuart Weller's Bibliographic Index of North American Carboniferous Invertebrates have been followed.

PLATE VIII

1. *Glossina waverlyensis* Herrick, Limestone Hollow, Flint Ridge.
2. *Orbiculoidea convexa* (Shumard), Bald Knob.
3. *Orbiculoidea missouriensis* Shumard, Cannel Coal Mine, Flint Ridge.
4. *Orthothetes crassus* (Meek and Hayden), Bald Knob.
5. *Chonetes mesolobus* Norwood and Pratten, ventral valve, x 2, Cannel Coal Mine, Flint Ridge.
6. *Chonetes mesolobus* Norwood and Pratten, dorsal valve, x 2, Cannel Coal Mine, Flint Ridge.
7. *Productus longispinus* Sowerby, Limestone Hollow, Flint Ridge.
8. *Spiriferina kentuckiensis* (Shumard), Bald Knob.
9. *Spirifer camaratus* Morton, Somerset.
10. *Spirifer rockymontanus* Marcou, Somerset.
11. *Reticularia perplexa* (McChesney) Bald Knob.
12. *Seminula argentea* (Shepard), ventral valve, Cannel Coal Mine, Flint Ridge.
13. *Seminula argentea* (Shepard), dorsal view, Limestone Hollow, Flint Ridge.
14. *Soleniscus klipparti* Meek, Limestone Hollow, Flint Ridge.

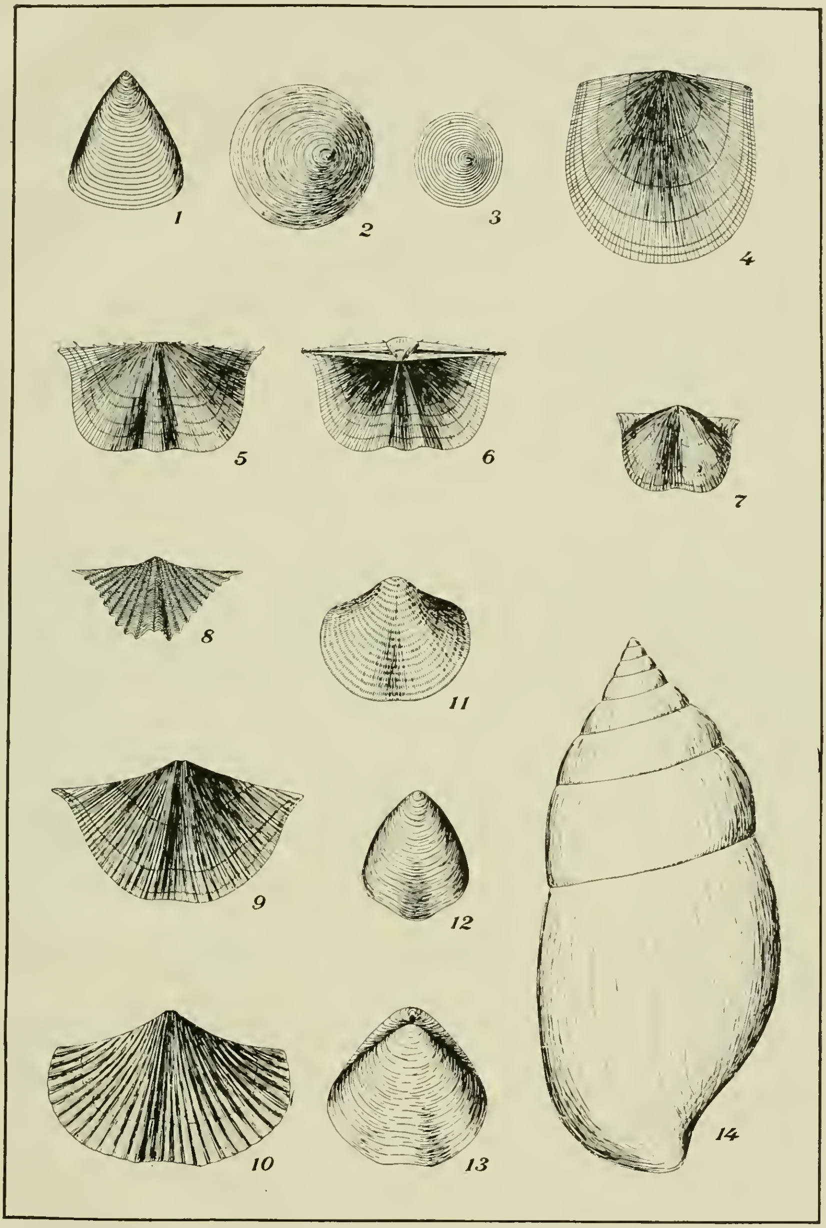
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PLATE IX

1. *Solenomya radiata* Meek and Worthen, Somerset.
2. *Solenomya anodontoides* Meek, Limestone Hollow, Flint Ridge.
3. *Edmondia reflexa* Meek, Cannel Coal Mine, Flint Ridge.
4. *Edmondia nebrascensis* Geinitz, Bald Knob.
5. *Leda bellistriata* Stevens, x 2, Limestone Hollow, Flint Ridge.
6. *Yoldia stevensonia* Meek, Limestone Hollow, Flint Ridge.
7. *Parallelodon carbonarius* Cox, Cannel Coal Mine, Flint Ridge.
8. *Parallelodon tenuistriatus* Meek and Worthen, Bald Knob.
9. *Parallelodon obsoletus* Meek, Cannel Coal Mine, Flint Ridge.
10. *Parallelodon sangamonensis*, Bald Knob.
11. *Avicula ohioensis* Herrick, Cannel Coal Mine, Flint Ridge.
12. *Myalina swallovi* McChesney, x 2, Bald Knob.
13. *Schizodus cuneatus* Meek, Limestone Hollow, Flint Ridge.
14. *Schizodus curtus* Meek and Worthen, Cannel Coal Mine, Flint Ridge.

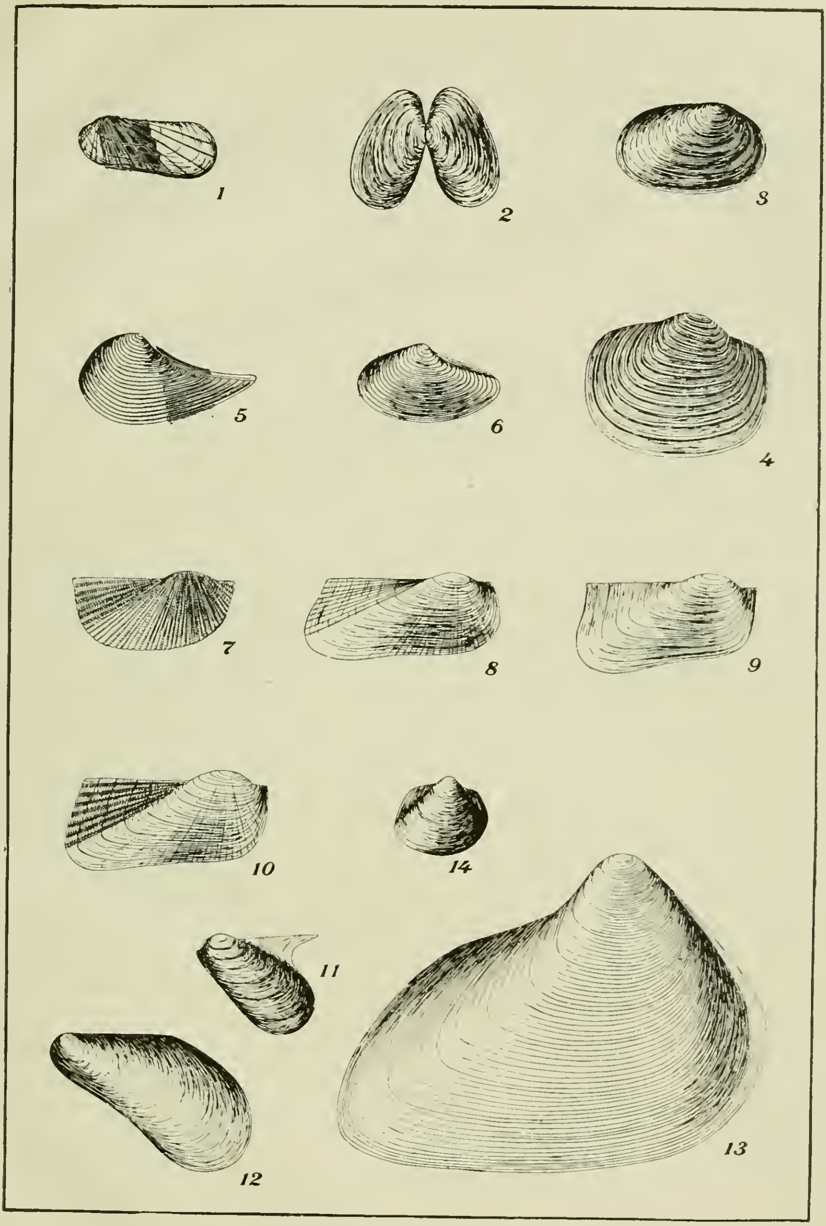
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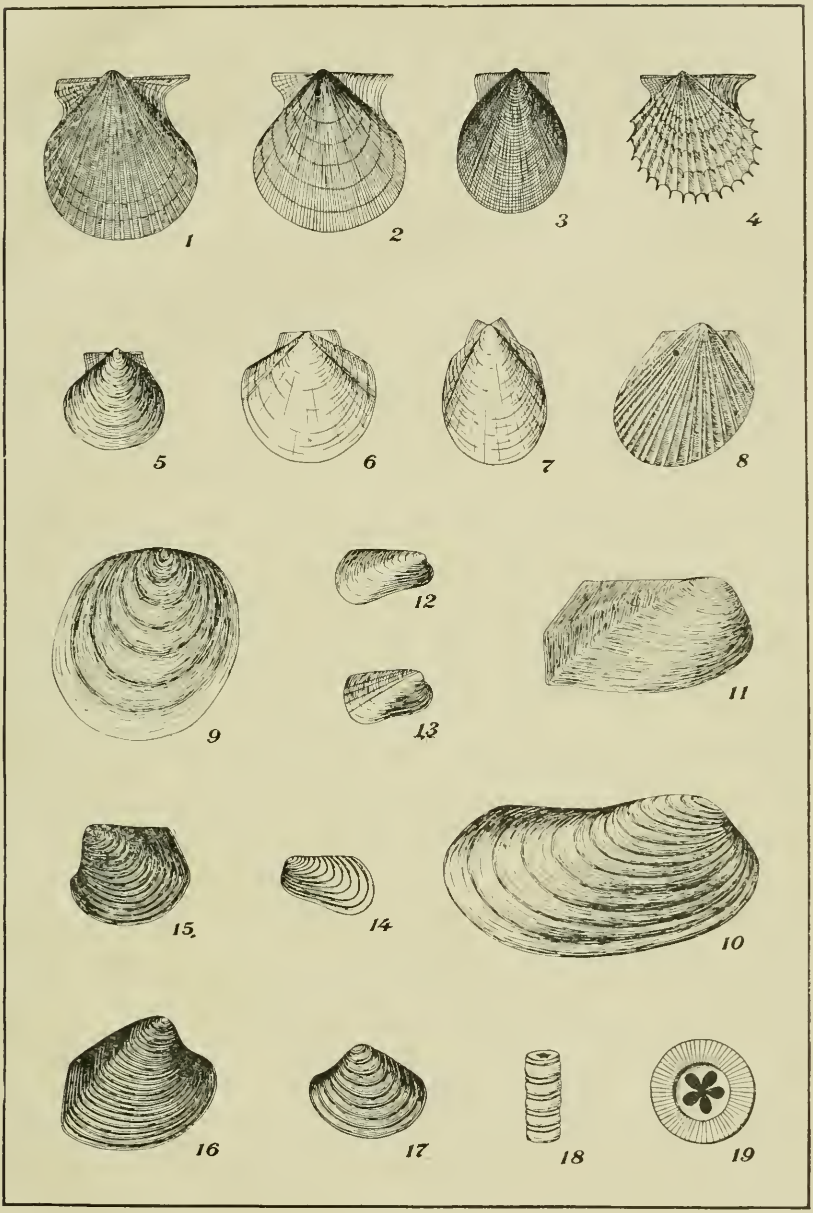
PLATE X

1. *Aviculopecten coxanus* Meek and Worthen, x 2, Cannel Coal Mine, Flint Ridge.
2. *Aviculopecten occidentalis* (Shumard), x 2, Bald Knob.
3. *Aviculopecten herzeri* Meek, x 2, Somerset.
4. *Acanthopecten carboniferus* (Stevens) Bald Knob.
5. *Euchondria neglecta* Geinitz, x 2, Bald Knob.
6. *Pecten* (*Entolium*) *aviculatus* (Swallow) Limestone Hollow, Flint Ridge.
7. *Entolium attenuatum* Herrick, Cannel Coal Mine, Flint Ridge.
8. *Lima retifera* Shumard, x 2, Limestone Hollow, Flint Ridge.
9. *Placunopsis carbonaria* Meek and Worthen, Cannel Coal Mine, Flint Ridge.
10. *Allorisma terminale* Hall, Cannel Coal Mine, Flint Ridge.
11. *Pleurophorus tropidophorus* Meek, Limestone Hollow, Flint Ridge.
12. *Pleurophorus oblongus* Meek, Bald Knob.
13. *Pleurophorus subcostatus* Meek and Worthen, Limestone Hollow, Flint Ridge.
14. *Cypricardinia carbonaria* Meek, Bald Knob.
15. *Astartella vera* Hall, Limestone Hollow, Flint Ridge.
16. *Astartella newberryi* Meek, Cannel Coal Mine, Flint Ridge.
17. *Astartella varica* McChesney, Limestone Hollow, Flint Ridge.
18. Crinoid segments, Somerset.
19. Crinoid segment, Fultonham.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A STUDY OF THE SUPPOSED HYBRID OF THE BLACK AND SHINGLE OAKS[1]

(*Contribution from the Botanical Laboratory of Denison University, No. XI*)

EARL HARRINGTON FOOTE

Historical sketch of Quercus Leana........ 316
Description of Cedar Point representatives........ 318
Gross anatomy of the stem........ 321
Microscopic studies........ 322
Quercus imbricaria
Transverse........ 323
Tangential........ 324
Radial........ 324
Quercus velutina
Transverse........ 325
Tangential........ 325
Radial........ 326
Quercus Leana
Transverse........ 326
Tangential........ 326
Radial........ 326
Summary of microscopic studies........ 327
Comparison with the type tree and others........ 327
Conclusions........ 330

HISTORICAL SKETCH OF QUERCUS LEANA

Quercus Leana Nutt., a supposed hybrid between the two species *Q. imbricaria* Michx. and *Q. velutina* Lam., received its name from Mr. T. G. Lea who discovered a single specimen near Cincinnati, Ohio, about seventy or eighty years ago. A part of Lea's description of the tree reads as follows:

> If a hybrid, it may have come from the *Q. imbricaria* or *Q. tinctoria* (*velutina*) or *Q. coccinea*. The fruit is too widely different from *Q. rubra*. The peduncles are about the same length as in my specimens of *Q.*

---

[1] Work done under the direction of Prof. Malcolm E. Stickney as part requirement for the degree of Master of Science, Denison University.

imbricaria. The petioles are much longer than in *Q. imbricaria*, the leaves larger and more obtuse at base. These modifications (if it is a hybrid) may be derived from the long petioles and larger leaves of the black and scarlet oaks. I have found but a single stock of this (about five years ago). It grows three miles north of Cincinnati.[2]

Thomas Nuttall,[3] in commenting on these lines differed with Mr. Lea, expressing the belief that the new oak was a distinct species allied to the black or red oak. He said,

> I confess I see too little resemblance in our plant with *Quercus imbricaria* to agree with my friend, Mr. T. G. Lea, as to any hybrid connection with that remotely allied species. Betwixt the gray oak (*Q. ambigua* Mich.), and *Q. tinctoria* I perceive a nearer resemblance. The fruit appears to be wholly that of the gray oak. The gland in both is striated and with a small conic projection. In our plant, however, the base of the gland and that of the cup are yellow, indicating its alliance to *Q. tinctoria.* The leaf differs wholly from both in its simple undivided lobes, though the long petioles and rounded base is that of *tinctoria.* Scarce as this species yet appears to be, under the present circumstances, I am inclined to believe it is of a distinct race, with features as distinct as any species in the genus; for the gray oak, being, I believe, unknown in Ohio, is again out of the question. I suspect it is in all physical respects allied to *tinctoria* and would equally afford a yellow dyeing material.
>
> The full grown leaves are from five to five and a half inches long by three to three and a half wide, smooth and shining above, with a small quantity of deciduous stellate pubescence beneath. The lobes are about a single pair on a side, the central lobe only sometimes again subdivided into three lesser lobes all of them ending in bristles. The base is rounded, and often hollowed out, or somewhat sinuated. The buds are small and brown. The fertile flower often by threes, on a short, thick common pedicel, the middle flower abortive. Male flowers not seen. Cups rather deep, as in *Quercus tinctoria* with the scales ovate, obtuse, and closely imbricated. The acorn roundish, somewhat ovate, broadly striate, with short roundish conic point or umbo about half-way, or nearly so immersed in cup.

Some years later Lester F. Ward[4] discovered two trees in the District of Columbia which he identified as *Leana,* comparing them with the specimens in the Herbarium of the Department of Agriculture. He says:

---

[2] Nuttall, *North American Sylva,* vol. i, p. 25, 1865.

[3] *Ibid.*, pp. 25–27.

[4] *Field and Forest,* vol. i, p. 41, 1865.

> Two trees which I have recently discovered in a wood near the northwestern (northern) corner of the District of Columbia, have proved unusually interesting. That these should be called *Quercus Leana* and not *Q. heterophylla* I maintain for the following reasons: Their resemblance to *Q. heterophylla* as it exists in the Herbarium of the Department of Agriculture is not sufficiently close to warrant this name, the leaves being broader and less lobed. They do agree substantially with the specimens of *Q. Leana* in that herbarium. They do agree remarkably well with the tree which Mr. W. R. Smith, Supt. of the U. S. Botanical Gardens, has raised in his grounds from an acorn of *Q. imbricaria*. Finally on considering the locality in which these trees were found, it seems impossible to believe that *Q. Phellos* can have entered into the combination. In the entire wood where they are situated not an individual of that species exists. It is wholly wanting throughout the region of Rock Creek on which the grove is located. On the contrary the prevailing oak there is *Q. imbricaria* although both varieties of *Q. coccinea* are also frequent. It cannot therefore be justly claimed that this new discovery constitutes a revival of the famous Bartram oak, since this was decided on the highest authority to be either a form of *Q. Phellos* or a union of that species with *Q. coccinea* var. *tinctoria*. It is none the less however a botanical curiosity.

Sargent[5] next takes up the subject and says:

> This tree has generally been considered a natural hybrid between *Q. imbricaria* and *Q. coccinea* or *Q. tinctoria*. It is now known in several widely scattered localities, from the neighborhood of Washington, D. C. to Missouri, and there seems no reason . . . . why, if *Q. heterophylla*, which many excellent observers have always considered a hybrid, is included as a species in the American Sylva, *Q. Leana* should not be included also. It should follow immediately after *Q. imbricaria* with which its relationship is obvious.

Following this I can find no mention of *Q. Leana* until 1909 when Mr. Saur[6] gives a description of the three trees, *imbricaria*, *velutina*, and *Leana*, and notes the following facts pointing toward the conclusion that *Leana* is a hybrid between *velutina* and *imbricaria:*

> 1. Hundreds of acorns have been planted but there is no record of one having germinated.
> 2. The leaves closely resemble those of the shingle oak.
> 3. The few specimens discovered are isolated from each other.
> 4. The cup and the fruit bear marked resemblance to those of the black oak.

---

[5] *Garden and Forest*, vol. ii, p. 471.

[6] *Plant World, vol. 12*, No. 9, Sept., 1909.

Sargent[7] in his *Sylva of North America* gives *Leana* a place with *imbricaria*; and in his *Trees of North America*, he says[8] that *Q. Leana* is believed to be a hybrid between *Q. imbricaria* and *Q. velutina*. Britton in his "*Flora of United States and Canada*,"[9] says that *Q. Leana* is a hybrid between *Q. imbricaria* and *Q. velutina*, while the new Gray manual makes no mention of it whatever.

Historically then we see that Nuttall is the only one to consider *Leana* a distinct species, and that the other men have considered it a natural hybrid between *imbricaria* and either *velutina* or *coccinea*. Mr. Ward favored *coccinea*, but the later men, Sargent and Britton, have returned to Lea's first suggestion and have considered *velutina* the other parent. Lea mentions *Q. rubra* but disproves the possibility of it having entered into the combination, their fruits differing widely. Mr. Nuttall mentions *Q. ambigua*, the gray oak, and his statement that the fruit "appears to be wholly that of the gray oak" can be neglected because the gray oak is no longer recognized as a species. Mr. Ward mentions *Q. Phellos* and gives the reason for not considering it that it was not found in the locality of his hybrids. It is not found in the vicinity of Cedar Point and need not be considered here.

Description of Cedar Point Representatives

On Cedar Point there are several trees that have been considered by the late Professor Kellerman, Professor Jennings and others to be representatives of Lea's oak. Cedar Point is an almost isolated piece of land and while oaks are very abundant there, they are confined to practically three species: *imbricaria*, *velutina*, and *rubra*. These with one or two representatives of *macrocarpa* and the half dozen or so representatives of Lea's oak mentioned above complete the list. Professor Moseley[10] mentions one oak of a hybrid nature which he suggests may be a cross between *imbricaria* and *Marilandica*. In 1910 a tree was found by Mr. Simkins several miles southeast of the Laboratory, which may answer to this description.

---

[7] Vol. viii, p. 176, 1895.

[8] P. 252, 1905.

[9] Vol. i, p. 520, 1896.

[10] *Sandusky Flora*, p. 73, 1899.

In 1910 Professor Jennings called my attention to another oak which shows hybrid characters. The leaves resemble those of *velutina* and have long yellowish petioles which show plainly when one is approaching the tree, giving it a striking appearance. Some of the leaves are less lobed than others and all show a characteristic curve in the vertex of the lobe. Seedlings close by indicate that its fruit which is like that of *velutina* is fertile.

Since I have studied two of these trees identified as *Leana* more closely than the others it may be well to describe them in particular. One of them is on the top of a sand dune nearly midway between the lake and Beimiller's cove about a hundred and twenty yards north west of the State University Lake Laboratory. The tree is about twenty-five or thirty feet high, its trunk at the base about sixteen or eighteen inches in diameter. The tree is but little shaded, and its horizontal somewhat pendulous branches arise within six or seven feet from the ground. These almost touch the branches of an *imbricaria* just to the east. At present the tree is being covered with grape vines and a number of its branches are dying. This tree we may for convenience refer to as tree *A*. The other tree is perhaps thirty yards farther northwest and is nearer the cove. It is about forty feet tall, its trunk about twenty or twenty-two inches in diameter at the base. Its first horizontal somewhat pendulous branches arise about twelve or fifteen feet from the ground. The tree, situated in an *imbricaria* grove, is in a lower place than tree *A* and is in better condition. We may refer to this tree as tree *B*.

The general habit, rather smooth brownish bark, branching, and imbricated leaf arrangement of both trees resemble that of *imbricaria*. In tree *B* the angle between the branches and the trunk is more acute and the branches more ascending for a short distance. An examination of their leaves shows intermediate characters between the entire oblong-lanceolate or oblong-ovate leaves of *imbricaria* and the five to seven lobed obovate leaves of *velutina*. The most distinctive leaf is slightly obovate and three lobed, each lobe ending in a bristle. Some of the leaves are hardly to be distinguished from those of *imbricaria* while others are quite deeply five to seven lobed. Where the leaves are entire or only slightly lobed their margins are often somewhat crisped. In shaded places very large leaves practically like the juvenile leaves of *velutina* are often found.

The leaves of tree *A* are smaller than those of tree *B* and the distinctive three lobed apex is often found, while in tree *B* the leaves are generally five or seven lobed and rarely show a three lobed apex. The leaves of tree *A* measure 8½ to 13 cm. by 3¾ to 8 cm.; those of tree *B*, 11 to 17½ cm. by 4 to 12½ cm. The petiole is longer than that in *imbricaria* and the base more obtuse, characters suggesting *velutina*. The leaves are arranged on the stem in a fashion very similar to those of *imbricaria* giving almost the characteristic shingle appearance. On a twig of a single year's growth the leaves at its beginning are lobed but not as deeply as those in the middle and toward the end, but at the end of the stem, contrary to what one would expect, there are usually one or more leaves which are entire and practically like *imbricaria* leaves (plates XI and XII). The young leaves of *imbricaria* are covered on the lower side with a thick hoary tomentum, while there is a scurfy pubescence on the upper side. In the bud of *imbricaria* the leaves are involute, while in *velutina* and *Leana* they are convolute. Sargent[11] mentions this.

In both trees of *Leana* the acorn, with its turbinate cup which has closely appressed hoary scales fringed at the rim, is more nearly like that of *velutina* than *imbricaria* and is so unlike that of *rubra* that the red oak is out of the question. The male flowers of tree *A* have peduncles that are intermediate in length between those of *imbricaria* and *velutina*, while the peduncles of tree *B* are equal in length to those of *velutina*. *Imbricaria* peduncles are about 4 cm. in length, *velutina*, 8 to 8½ cm., *Leana*, tree *A*, 6 to 6½ cm., and tree *B*, 8 to 9 cm.

Owing to the inaccessibility of Cedar Point continuous observation of the trees cannot be made from Granville, but on May 14, 1910, I found that the pistillate flowers of all three kinds had matured, and that good staminate flowers of *velutina* were very scarce, the anthers having shed their pollen in nearly all cases. Good specimens of staminate flowers of *imbricaria* and *Leana* were abundant. Therefore I conclude that the stigmas of the pistillate flowers on a tree ripen before the anthers of its staminate flowers, thereby securing cross fertilization. The slight difference in the time of maturity of the two kinds of flowers of *velutina* and *imbricaria* may be very significant. The first ripened pistils of *imbricaria* are ready for pollination before *imbricaria* pollen is available, but when there is an abundance of *velutina* pollen. Thus a favorable condition for hybridization is brought about, and at the same time the direction in which such hybridization will take place is strongly indicated. In other words *imbricaria* must be the maternal and *velutina* the paternal parent. Such an assumption is further borne out by the position of the trees in question at Cedar Point, all being near *imbricaria* trees, with *velutina* trees more or less distant. The assumption also is in harmony with Mr. Ward's account of a *Leana* raised by Mr. W. R. Smith from an acorn of *imbricaria.*

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[11] *Sylva of North America*, vol. viii, p. 176, 1895.

GROSS ANATOMY OF THE STEM

The oaks have characteristically a sharply five angled pith and conspicuous broad medullary rays. The pentagonal pith of the three oaks in question is decidedly asymmetrical, being considerably longer than broad. In *velutina* it is in general much larger than in the other two, and averages nearly twice as long as broad. The smaller pith of *imbricaria* has much the same shape, being both shorter and narrower. *Leana* has a greatly elongated and much compressed pith, thus presenting in one dimension the condition of *velutina,* and in the other that of *imbricaria* (plate XIV, figs. 1–3).

In small branches of *imbricaria,* 1 cm. in diameter, the broad rays are conspicuously arranged in pairs producing with the enclosed wood masses the appearance of five distinct radiating bands. Certain other oaks also possess this feature, noticeably the English oak (*Q. robur*), where the radiating bands are more narrow but equally conspicuous. *Velutina,* on the other hand, shows numerous large medullary rays in addition to the five pairs at the angles of the pith, and the bands, so striking in *imbricaria,* are hardly conspicuous here. *Rubra* and *coccinea* present much the same condition as *velutina* in this respect, although in *rubra* the rays are somewhat less distinct, and the bands even less evident, while in *coccinea* the more numerous rays are rather regularly distributed and the bands disappear altogether. *Leana* shows a condition strikingly like *velutina* save that the bands are more distinct (Plate XIII, figs. 1–8).

The composition of the annual ring presents certain significant features. The spring wood which in all three is not sharply defined, in *imbricaria* appears in the form of a fairly regular band of large tracheæ of nearly uniform size extending completely across the space between two broad medullary rays, with very little of wood masses included. In *velutina* the tracheæ are not so uniform in size and show a tendency to be grouped together in irregular shaped areas interspersed with wood masses. In *Leana* the vessels are perhaps more nearly uniform in size as in *imbricaria* but they show a tendency toward bunching as in *velutina*. The summer wood in *imbricaria* is nearly solid, broken rather inconspicuously by small amounts of wood parenchyma forming long narrow tangential lines. A few small tracheæ appear distributed radially. In *velutina* the masses of summer wood are as a rule relatively broader and are not nearly so dense, the blocks of wood fibres being broken up by the more numerous, broader and more conspicuous tangential bands of wood parenchyma. The summer wood in *Leana* presents a condition closely approximating that in *velutina* save that the tangential bands of wood parenchyma are slightly less numerous and the growth ring is not so wide. The growth ring is narrower in *imbricaria* than it is in either of the others.

MICROSCOPIC STUDIES

Sections in transverse, tangential, and radial planes were made with a sliding microtome from stems of various sizes up to $2\frac{1}{2}$ cm. in diameter. A part of these sections were cut from living material, the sections being transferred to 70 per cent alcohol and then brought into water for staining; and a part were made from material fixed in picro-corrosive and imbedded in celloidin according to Jeffrey's method.[12] All were stained with Ehrlich's hæmatoxylin and safranin.

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[12] *Botanical Gazette*, vol. xxxvii, pp. 456–461, 1904.

IMBRICARIA

Transverse (plate XIII, fig. 1; plate XIV, figs. 1, 4). The pith cells are generally roundish, rather loosely packed together, and fairly uniform in size. The broad pith rays are from three to seven cells in width in the first year's growth and broader in the older stems. The narrow rays, mostly a single cell in width, are poorly defined and inconspicuous. Extending out from between the groups of protoxylem next the pith are rays which begin with a width of three or four cells, but which quickly narrow to the dimensions of the ordinary narrow ray. In older stems secondary broad rays develop by the coalescence of narrow rays.[13] In the broad rays the cells are rectangular, narrow, elongated radially, with oblique tangential walls. In the narrow rays the cells are sometimes squarish in the spring wood, and come to be elongated radially in the summer wood. Protoplasmic connections appear rather conspicuously between the pith cells, between the ray cells, and between the two. Wood parenchyma is rather sparingly distributed among the tracheids and wood cells of the spring wood, and occurs in the summer wood as occasional wavy tangential bands. The cells are larger than the wood cells, are thin walled, roundish, and fairly uniform in size. The wood fibers are triangular to septagonal, largely pentagonal, and vary somewhat in size. In the spring wood they are thin walled and are distributed without special grouping among the large vessels and tracheids. In the summer wood they are massed in blocks of considerable size which are penetrated by occasional tracheids, and bounded by the medullary rays and bands of wood parenchyma. A fairly distinct radial arrangement of the fibers can be made out, which becomes definite with the squarish cells at the outer margin of the sharply defined growth ring. Tracheids are fairly numerous in the spring wood, where they vary considerably in size and shape, being irregularly distributed among the wood parenchyma cells and wood fibers between the large vessels. In the summer wood they are less numerous, are circular in form, and are usually found close to the cells of the pith rays. They are thick walled, with numerous oval bordered pits. The vessels are almost wholly confined to the spring wood where they are large and nearly uniform in size, distributed in a single or at most a double row extending completely across the space between two broad medullary rays. Two vessels closely adjoining each other and even compound vessels are sometimes found (plate XIV, fig. 4). Tyloses are fairly numerous in some of the preparations studied. In the summer wood a few small vessels appear in loose radial chains, diminishing in size toward the outer part of the growth ring. Protoxylem is found next the central pith, in the form of small spiral vessels grouped in definite masses between the bases of the broad medullary rays. In the bast there is considerable development of sclerenchyma, which in young twigs occurs in the form of wavy bands just outside the sieve tissue (plate XIV, fig. 1). In older stems this band becomes broken.

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[13] Eames, *Botanical Gazette*, vol. xlix, pp. 161–167, 1910.

Tangential. The broad pith rays are frequently broken up by oblique strands of wood fibers or parenchyma cells, presenting a decidedly stringy appearance across the ray. These strands disappear in the older wood. The uniseriate rays are straight and parallel, and are rather long, being from three to thirty cells in length, and averaging from ten to fifteen cells long. The cells are roundish, somewhat elongated vertically. The wood parenchyma cells are rectangular, being three times as long as broad. The wood fibers are narrow and straight. The vessels are scalariform with bordered pits, and show occasional tyloses.

Radial (plate XIV, fig. 7). The pith cells are rectangular, with roundish corners, and are arranged in more or less definite wavy vertical rows, being elongated sometimes radially, sometimes vertically. Protoplasmic connections between the cells are prominent. The pith ray cells are similar in form, being irregularly elongated radially. They are one and one-half times as long as broad, and show conspicuous protoplasmic connections. The wood parenchyma cells are also rectangular, averaging nearly eight times as long as broad. Protoplasmic connections are abundant both among these cells and between them and the pith ray cells. The protoxylem vessels usually show two spirals, although occasionally small vessels are found with but a single spiral, and on the other hand the larger ones may have three.

VELUTINA

Transverse (plate XIII, fig. 2; plate XIV, figs. 2, 5). The pith cells are somewhat more variable in size than in *imbricaria*, and their arrangement gives a more compact structure, with smaller intercellular spaces. The narrow pith rays are much more numerous, and stand out sharply against the wood masses as crooked, irregular, uneven lines. The ray cells are a little broader and somewhat longer, and more irregular. Protoplasmic connections occur as in *imbricaria*. Wood parenchyma is more abundant throughout both spring and summer wood, and in the latter is scattered in numerous wavy short tangential chains. Wood fibers are more abundant in the spring wood, especially near the broad rays. In the summer wood they are grouped in smaller masses, giving that part of the growth ring a much less compact and solid appearance. The radial arrangement of the fibers discernable in *imbricaria* is more or less broken up by masses of wood parenchyma, and the growth rings are not so sharply defined. Angular tracheids are plentiful in the spring wood, and roundish ones are scattered sparingly through the summer wood. The vessels of the spring wood are not so abundant or so large as in *imbricaria*, and do not extend so uniformly or so completely across the spaces between the broad medullary rays, but have a tendency to be bunched together into irregular groups. The few summer vessels are somewhat smaller than those of *imbricaria*. Compound vessels, or two vessels closely adjoining, are seldom found in *velutina*. The protoxylem is not massed into a few well-defined areas, as in *imbricaria*, but is scattered, appearing as numerous small groups of a few cells each. The sclerenchyma of the bast, which appears as a band in young twigs and which in *imbricaria* was merely sinuate, is here deeply scalloped.

Tangential (plate XIII, fig. 9; plate XIV, fig. 8). The broad pith rays of the younger stems present a more broken aspect than in *imbricaria*, being traversed with sheets of woody fibers instead of strands. Accordingly the stringy appearance noted in that species is quite wanting here. The uniseriate rays are more numerous than in *imbricaria*, and they average considerably shorter—from five to nine cells. They are not so straight or so uniformly parallel, and their distribution is not so regular. Occasionally they are two cells in width in the middle of a ray.

The wood parenchyma cells and also the wood fibers average somewhat larger in *velutina*, and the latter are not so straight. The vessels show fewer tyloses.

Radial. The pith cells in their vertical arrangement show something of the regularity seen in *imbricaria*, but their greater variability in size and form makes the rows of cells less even and distinct, and the wavy zigzag character of these rows is more pronounced. The pith ray cells average somewhat longer and wider, and tend to be more strictly rectangular, with straighter thicker walls. The wood parenchyma cells average somewhat larger.

LEANA

Transverse (plate XIII, fig. 3; plate XIV, figs. 3, 6). The pith cells in their arrangement present a fairly compact structure, as in *velutina*, but in uniformity of size and shape they are more like *imbricaria*. The uniseriate medullary rays are straight and rather inconspicuous, thus resembling *imbricaria*. The cells, however, are broader and more irregular, as they are in *velutina*. The wood parenchyma is altogether *velutina* like, both in its distribution and arrangement. The radial arrangement of the wood fibers is maintained here, as in *imbricaria* despite the fact that the numerous blocks of wood parenchyma would naturally tend to break it up. Angular tracheids are abundant in the spring wood, while a few roundish ones are to be found embedded in the wood masses of the later growth. The vessels are altogether *velutina* like, in abundance, distribution, and arrangement. The protoxylem is perhaps somewhat less scattered than in *velutina*, but shows none of the distinct massing characteristic of *imbricaria*. In the bast of young stems the band of sclerenchyma presents the deeply scalloped appearance of *velutina*.

Tangential. The broad medullary rays of the younger stems present in their interruption by obliquely running strands, a condition closely resembling that in *imbricaria*. The narrow rays in their number, size, character, arrangement and distribution, are altogether like *velutina*, as are also both the wood parenchyma and the wood fibers. Tyloses occur abundantly in the vessels in some of the preparations studied.

Radial (plate XIV, fig. 9). The arrangement in vertical rows of the pith cells is more distinct and even, and less wavy and zigzag than in *velutina*, and closely simulates the condition in *imbricaria*. The medullary cells are usually broad, as in *velutina*, although occasional narrow ones are to be found. The ray cells tend to be rectangular, with straight thick walls, here again as in *velutina*. The wood parenchyma cells vary widely in size, both the large ones of *velutina* and the smaller ones of *imbricaria* being here present.

SUMMARY OF MICROSCOPIC STUDIES

From these anatomical studies it appears that, while certain features show remarkable uniformity in form and structure, differences do appear in the size, number, and arrangement of parts. In all these respects it is seen that *Leana* resembles either *imbricaria* or *velutina*, rarely occupying an intermediate position between them. From the table it will be seen that *Leana* resembles *velutina* in the distinctive features of the following characters: annual ring, spring and summer wood, broad rays, broad and narrow ray cells, pith (arrangement of cells), wood parenchyma, wood fibers, vessels (distribution), protoxylem (arrangement), and sclerenchyma of bast. It resembles *imbricaria* in pith cells (size), five bands, narrow medullary rays, some of the wood parenchyma cells, vessels (size), and in tyloses.

Penhallow[14] shows in an anatomical study of Teas hybrid Catalpa that the structural features of the two parents are faithfully transmitted to the offspring. If what Penhallow found to be true for Catalpa obtains in oaks, we have a right to conclude that resemblances such as appear between the oaks in question have a significance in demonstrating actual relationship. In other words, these resemblances furnish a strong evidence of the hybrid nature of Lea's oak.

Comparison With the Type Tree and Others

Leaves of the type tree in general resemble very closely those from the Cedar Point trees, although differing in certain respects. The latter leaves are often more deeply lobed, and their bases tend to be less obtuse than the former. On the other hand,

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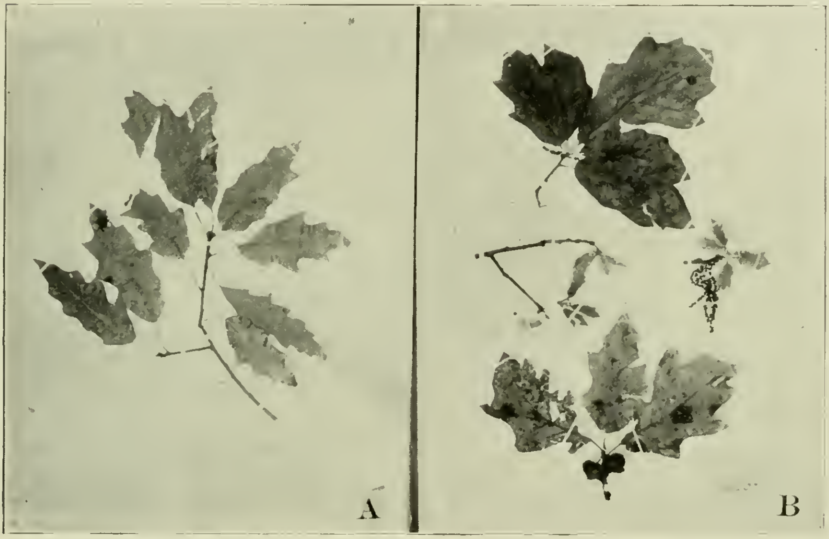
[14] *American Naturalist*, vol. xxxix, No. 459, pp. 113–136, 1905.

	IMBRICARIA	VELUTINA	LEANA
Annual rings	Sharply defined	Poorly defined	Poorly defined
Spring wood	Coarse, uniform	More compact, not uniform	More compact, not uniform
Summer wood	Solid, compact, narrow	Broken, broad	Broken, less broad
Pith	Small	Large	Long and narrow
Pith cells	Loosely packed uniform size	Closely packed variable size	Closely packed uniform size
	Even vertical rows, wavy	Uneven vertical rows zigzag	Fairly even rows, wavy
Broad pith rays	Five pairs, forming bands	Numerous, no bands	Numerous, bands
	Broken by strands	Broken by sheets	Broken by both
Cells	Narrow with oblique walls	Wider, more strictly rectangular	Broad, rectangular
	Thin walls	Thick walls	Thick walls
Narrow pith rays			
(transverse)	Straight, parallel, inconspicuous	Crooked, not parallel, conspicuous	Straight, parallel, inconspicuous
(tangential)	Long, few, regularly distributed	Short, numerous, irregularly distributed	Short, numerous, irregularly distributed
Cells	Uniform, small	Irregular, larger	Irregular, larger
Wood parenchyma	Scarce in spring wood	More abundant in spring wood	More abundant in spring wood
	Narrow bands in summer wood	Broader masses in summer wood	Broader masses in summer wood
Cells	Smaller	Larger	Some larger, some smaller
Wood fibers	Distinct radial chains	Broken radial chains	Distinct radial chains
Cells	Smaller, straight	Larger, not straight	Larger, not straight
Vessels	Inter-ray space filled uniform layer	Space not filled Bunched	Space not filled Bunched
	Large, uniform size	Smaller, various sizes	Smaller, somewhat uniform
Protoxylem	Massed	Scattered	Somewhat scattered
Bast sclerenchyma	Wavy band	Deeply scalloped	Deeply scalloped
Tyloses	Sometimes many	Fewer	Sometimes many

specimens from Chickering (fig. 1, *A*) and Ward (plate XII, fig. 4) show a condition of greater acuteness than do the leaves from Cedar Point. Again, the margins between the lobes of the leaves of the type tree show a tendency toward rolling back which is not characteristic of the Cedar Point forms, or of any other representatives of this oak that have come under my notice. Taken all in all, however, the Cedar Point leaves approach nearer the type than any other forms examined.

The acorns compare very closely in all the forms examined. The transversely cut stem of Lea's tree shows the five distinct bands bounded by the ten primary pith rays coming off at the angles of the pith, as noted for *imbricaria*, and as found in the Cedar Point *Leana*. There are also a few additional broad rays, which, although fewer in number than the Cedar Point specimens show, are equally distinct (plate XIII, fig. 6). Further study of the stems has not been made.

In considering these observations it must be noted that in respect to leaf characters the Cedar Point trees show wide variability, including differences in form, outline, lobing, apex, base, and petiole. Accordingly it would be unreasonable to expect that differences might not exist between them and the type tree. Furthermore, an equally wide variability could be shown to exist in *velutina*, as found at Cedar Point and elsewhere, and could doubtless be demonstrated for many other oaks. In fact, if *Leana* be a hybrid, with *velutina* in its parentage, it would be altogether reasonable to suppose that the offspring had received this character of instability, along with other qualities in its inheritance. So neither from leaf characters, nor from structural features so far as studied, does evidence appear to preclude the placing of the Cedar point representatives in the same category with Lea's type tree.



A. *Quercus Leana* from Washington, D. C. Branch showing leaves. J. W. Chickering, Jr; × $\frac{2}{13}$.

B. *Quercus Leana* from Belleville, Ill. Branches showing leaves, flowers and fruit. George Engelmann; × $\frac{2}{13}$

CONCLUSIONS

The facts herein presented seem amply to justify the conclusion that the several trees at Cedar Point are hybrids between the *Quercus imbricaria* and the *Quercus velutina* found there, and that the type tree and others like it are hybrids between *imbricaria* and *velutina* because:

1. The fruit is sterile so far as is known.

2. The leaves are intermediate between those of *velutina* and *imbricaria.*

3. The stem in both gross and microscopic anatomy shows characters indicating relationship with both *imbricaria* and *velutina.*

4. The fruit is very much like that of *velutina* and is wholly unlike that of *Q. rubra.*

5. The staminate flowers of *velutina* are mature at the proper time for effecting cross pollination.

6. The trees are invariably isolated from each other and are always found by the side of an *imbricaria.*

Furthermore from the last two facts given, together with Mr. Ward's account of the *Leana* raised from an acorn of an *imbricaria* tree, we may conclude that the maternal parent is *imbricaria,* and the paternal, *velutina.*

ACKNOWLEDGMENTS

I wish to acknowledge my indebtedness and express my appreciation to Professor Stickney for his assistance in every part of this work. I also wish to thank Miss Lett, and Dr. Holden for the material from the type tree, and Professor Jennings, of the Carnegie Museum, for the loan of other specimens of *Leana.*

PLATE XI

FIG. 1. *Quercus imbricaria* from Cedar Point, O. Branch showing leaves and fruit; × $\frac{1}{6}$.

FIG. 2. *Quercus velutina* from Cedar Point, O. Branch showing leaves and fruit; × $\frac{1}{6}$

FIG. 3. *Quercus Leana* from Cedar Point, O., tree *A.* Branches showing leaves; × $\frac{1}{6}$.

FIG. 4. *Quercus Leana* from Cedar Point, O., tree *B.* Branch showing leaves. The entire leaf at the end of the branch has a wavy margin and is crisped; × $\frac{1}{6}$.

SUPPOSED HYBRID OF THE BLACK AND SHINGLE OAKS PLATE XI
Earl Harrington Foote

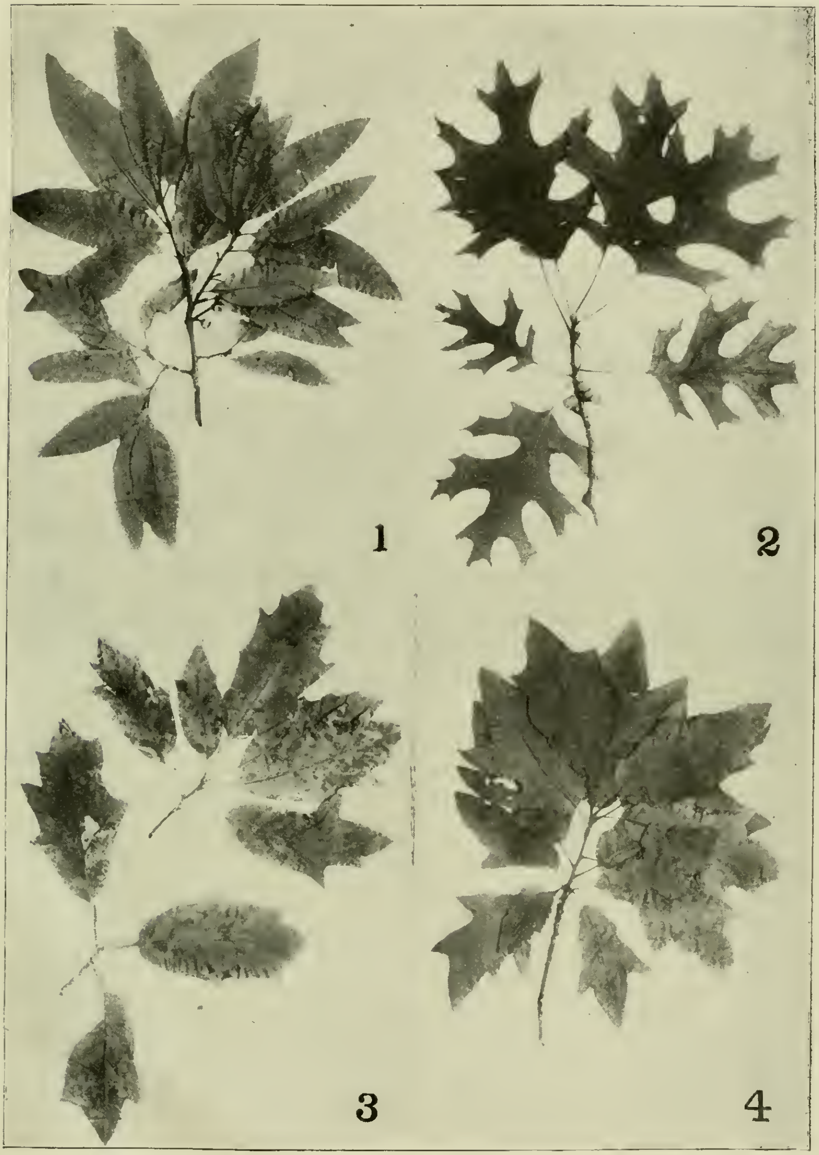


PLATE XII

FIG. 1. *Quercus Leana* from Cedar Point, O., tree *B*. Branch with imbricated leaves; entire leaves at end of year's growth; × $\frac{1}{6}$.

FIG. 2. *Quercus Leana* from Cedar Point, O., tree *B*. Branch showing leaves resembling juvenile leaves of *velutina*; × $\frac{1}{6}$.

FIG. 3. *Quercus Leana* from Cincinnati, O. Leaves from the type tree, × $\frac{1}{6}$.

FIG. 4. *Quercus Leana* from Washington, D. C. Branches showing leaves, flowers, and fruit. Lester F. Ward; × $\frac{1}{6}$.

SUPPOSED HYBRID OF THE BLACK AND SHINGLE OAKS
Earl Harrington Foote

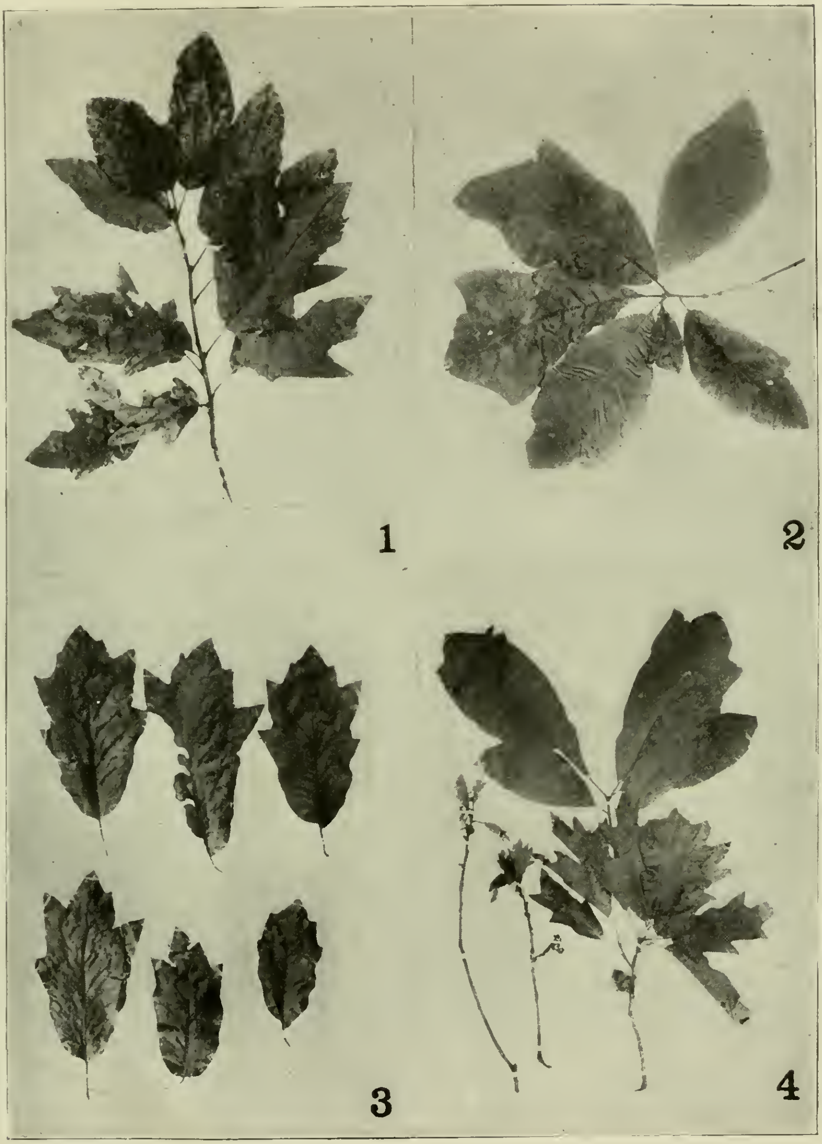


PLATE XIII

FIG. 1. *Quercus imbricaria* from Cedar Point, O. Twig (photographed through a hand lens) showing the five bands made by the five pairs of broad medullary rays and the enclosed wood; × 4.

FIG. 2. *Quercus velutina* from Cedar Point, O. Twig showing numerous broad medullary rays, five bands not distinct; × 4.

FIG. 3. *Quercus Leana* from Cedar Point, O. Twig showing numerous broad medullary rays; five bands somewhat distinct; × 4.

FIG. 4. *Quercus rubra* from Denison Campus. Twig showing numerous broad medullary rays; × 4.

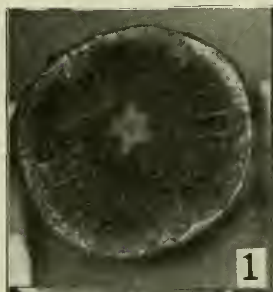
FIG. 5. *Quercus velutina* from Columbus, O. Twig showing numerous broad rays; × 4.

FIG. 6. *Quercus Leana* from Cincinnati, O. Twig from type tree, showing broad medullary rays; two pairs and their bands are prominent; × 4.

FIG. 7. *Quercus coccinea* from Denison Campus. Twig showing very numerous, less distinct, broad medullary rays; × 4.

FIG. 8. *Quercus alba* from Denison Campus. Twig showing wavy lines, no broad medullary rays; × 4.

FIG. 9. *Quercus velutina*. Tangential section showing protoplasmic connections between wood parenchyma cells; × 285.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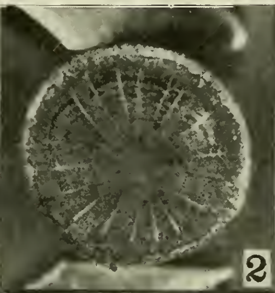
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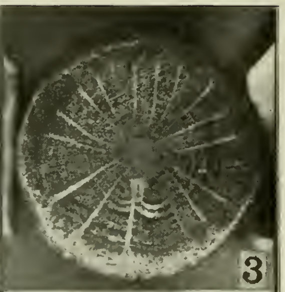
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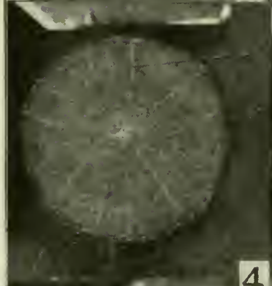
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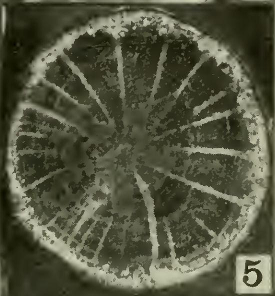
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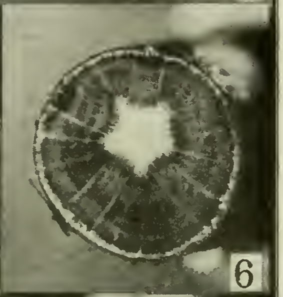
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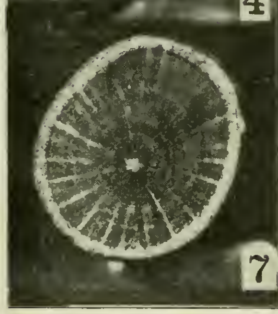
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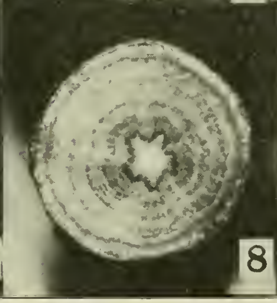
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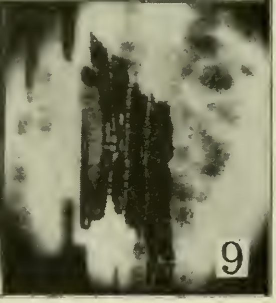
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PLATE XIV

FIG. 1. *Quercus imbricaria.* Transverse section showing small pentagonal pith and ring of sclerenchyma in bark: × 6.

FIG. 2. *Quercus velutina.* Transverse section showing very large pentagonal pith and deeply scalloped ring of sclerenchyma in bark: × 6.

FIG. 3. *Quercus Leana.* Transverse section, elongated, narrow pentagonal pith, and deeply scalloped ring of sclerenchyma in bark: × 6.

FIG. 4. *Quercus imbricaria.* Transverse section showing distinct annual ring, large uniform vessels in one or two rows in spring wood, few small vessels in radial chains in summer wood, broad medullary ray, uniseriate rays (inconspicuous), wood parenchyma cells in wavy tangential bands: × 285.

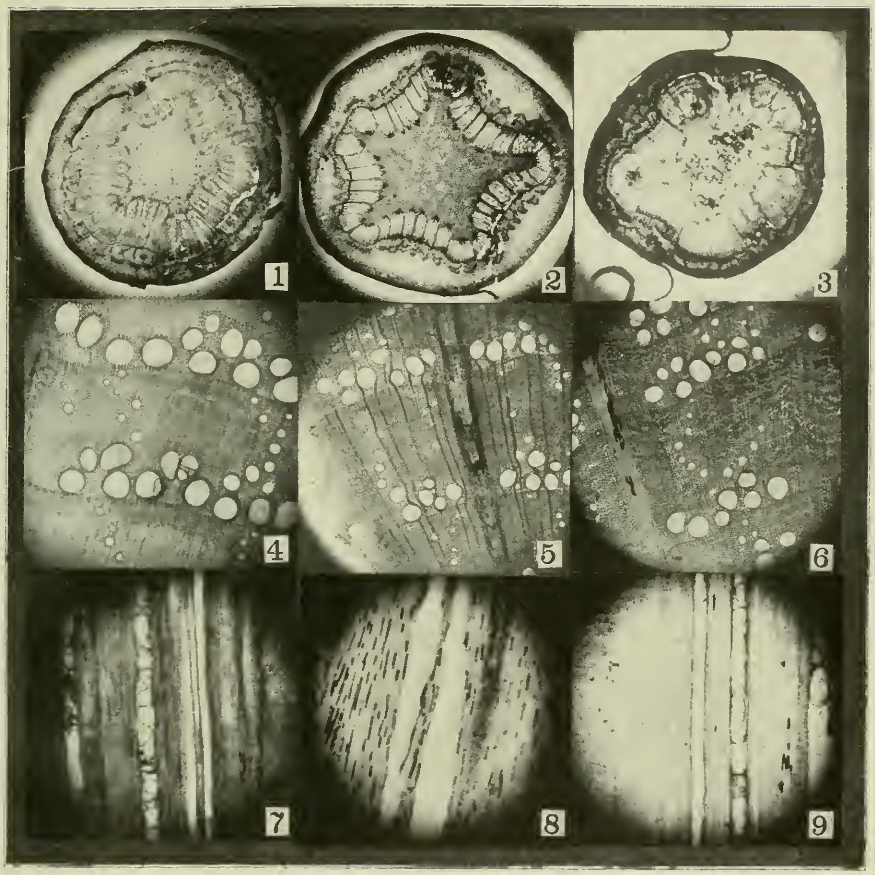
FIG. 5 *Quercus velutina,* Transverse section showing annual ring, smaller vessels varying in size in groups in spring wood, few small ones in radial chains in summer wood, broad medullary rays, prominent uniseriate rays, wavy tangential masses of wood parenchyma in summer wood; × 285.

FIG. 6. *Quercus Leana.* Transverse section showing annual ring, vessels showing tendency toward grouping, small ones distributed radially in summer wood, broad medullary rays, uniseriate rays (inconspicuous), wavy tangential masses of wood parenchyma in summer wood; × 285.

FIG. 7. *Quercus imbricaria.* Radial section showing vessels with numerous tyloses; × 285.

FIG. 8. *Quercus velutina.* Tangential section showing broad and uniseriate medullary rays, vessels without tyloses; × 285.

FIG. 9. *Quercus Leana.* Radial section showing vessel with tyloses; × 285.


1
2
3
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8
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A CASE OF PRE-GLACIAL STREAM DIVERSION NEAR ST. LOUISVILLE, OHIO[1]

Howard Clark

On account of the many interesting features in its drainage development, Ohio, in recent years, has attracted much attention among students of physiography. Among the first in Ohio to become interested was Dr. W. G. Tight,[2] who in a general way worked out some of the fossil stream courses of the central part of the state, and, in much detail, the drainage changes of southeastern Ohio, parts of Kentucky and West Virginia. In this work he dealt not only with the evolution of the Ohio River itself but also with the changes observed in many of its tributary valleys, especially in the Muskingum and Scioto valleys. In the western part of the state, Dr. J. A. Bownocker has studied several drift-buried channels, correlating them with a major stream that probably flowed to the west.[3] Several other workers have carried on similar studies in other parts of the state.

Many theories have been advanced in accounting for these changes in drainage: (a) piracy, (b) glaciation, and (c) diastrophism. In some cases more than one factor, it has been thought, was operative. But there is a lack of agreement among students of the subject in assigning relative weights to these factors. Dr. Tight[4] urged glaciation as the principal cause for the reversals in Ohio; Mr. Leverett[5] also gives much weight to this factor. Dr. Carney[6] concludes from more recent studies in parts of

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[1] This work was done under the direction of Professor Carney, as an assignment in an undergraduate course.

[2] U. S. Geol. Surv., *Professional Paper, No. 13*, 1902.

[3] *American Geologist*, vol. xxii, pp. 178–182, 1899. Ohio Academy of Science, *Special Paper, No. 3*, pp. 32–45, 1900.

[4] *Bull. Sci. Lab. Denison Univ.*, vol. viii, pt. II, pp. 35–61, 1894.

[5] U. S. Geol. Surv., *Monograph xli*, pp. 196–198, 1902.

[6] *Bull. Sci. Lab. Denison Univ.*, vol. xiii, pp. 139–153, 1907, vol. xiv, pp. 128–134, 1909.

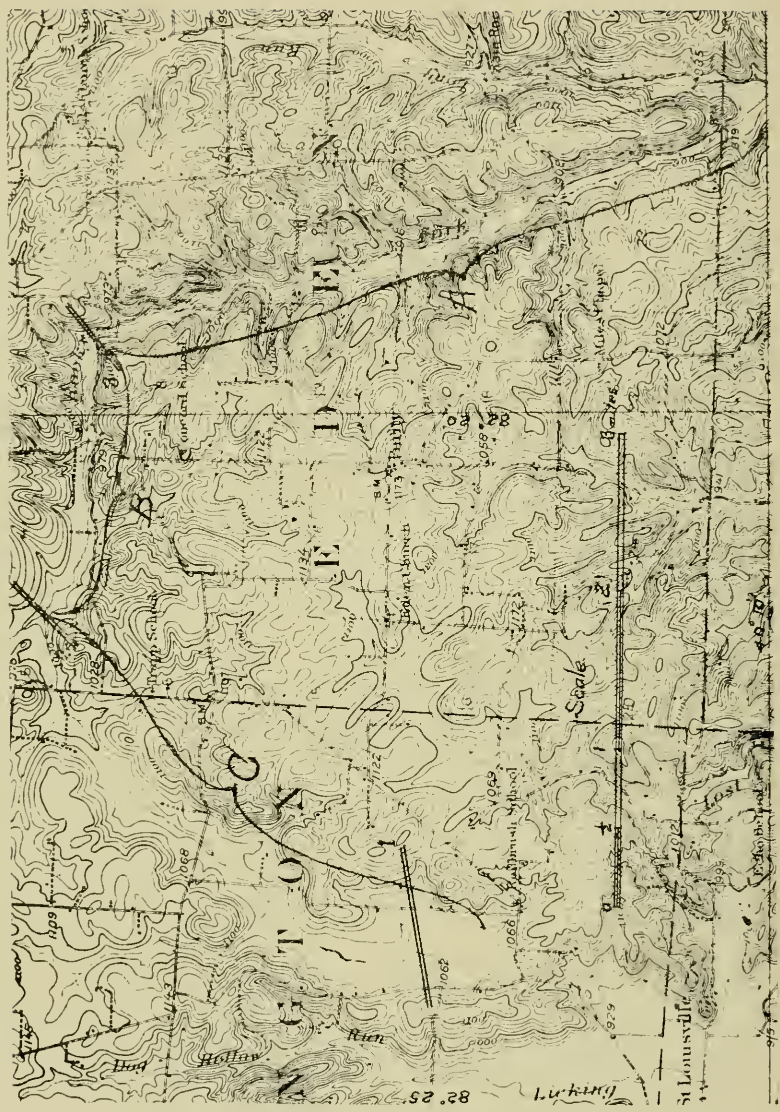
Scale
Licking
82° 25'
Run
Hollow

Fig. 1. Portion of the Newark topographic sheet. The three sets of parallel lines locate the cross-sections drawn in fig. 4.

Licking county that the stream reversals in this area were accomplished pre-glacially as a result of a differential land movement; Mr. E. R. Scheffel,[7] from work on drainage changes near Granville, Ohio, and Mr. K. F. Mather,[8] from a similar study of the Licking river near the "Narrows," confirm this theory.

The present discussion proposes no new theories concerning drainage changes; it directs attention to a case of reversal in which glaciation may, to some extent, be a factor.

DISCUSSION

The region here considered, a portion of Licking County, Ohio, contains the head-water area of Rocky Fork which has its source near the east wall of the North Fork of the Licking Valley, about one and one-half miles northeast of St. Louisville. From is place of origin the Rocky Fork flows in a northeasterly direction for about three miles, turning then to the east for two miles, continuing thence approximately south, and joining the Licking River near Hanover.

The Rocky Fork rises in a mature valley whose walls gradually converge down-stream, coming closest together about six miles from its source, where the present stream flows for some distance through a narrow gorge; below this narrow segment, the walls diverge to the south. Thus both up-stream and down-stream from the gorge is a wider valley.

The topographic map of this region (fig. 1) suggests that segments C and B of the Rocky Fork Valley were once connected with the Licking; the trend of this portion of the valley, and the fact that its walls flare towards the Licking Valley at St. Louisville are the obvious details which support such an inference. The stream which carved these segments flowed westward from near the eastern end of B.

But such irregularity in the width of a valley is sometimes the result of varying hardness in the rock horizons through which the stream is cutting. The rock structure itself, in this area, is not of a nature that gives such differential responses to weathering; the formations exposed are the Pottsville, Logan, and Black Hand, none of which are here very resistant.

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[7] *Bull. Sci. Lab. Denison Univ.*, vol. xiv, pp. 162–174, 1909.

[8] *Ib.*, pp. 183–187.

Evidently the Rocky Fork, in parts B and C, shows reversal; six miles of the valley that formerly carried a westward flowing stream now carries a stream flowing in the opposite direction. What caused this reversal?

The drift barrier. Just east of St. Louisville, at the junction of part C with the Licking, is a heavy deposit of glacial drift which forms a barrier across the mouth of the former valley; this moraine barrier has about the same altitude as the valley walls which bear a veneer of till. The barrier presents a steep and irregular front to the south, (fig. 3, *A*) the ice-contact side, while its northern front blends into an outwash plain which slopes gently and very regularly into the valley (fig. 2).

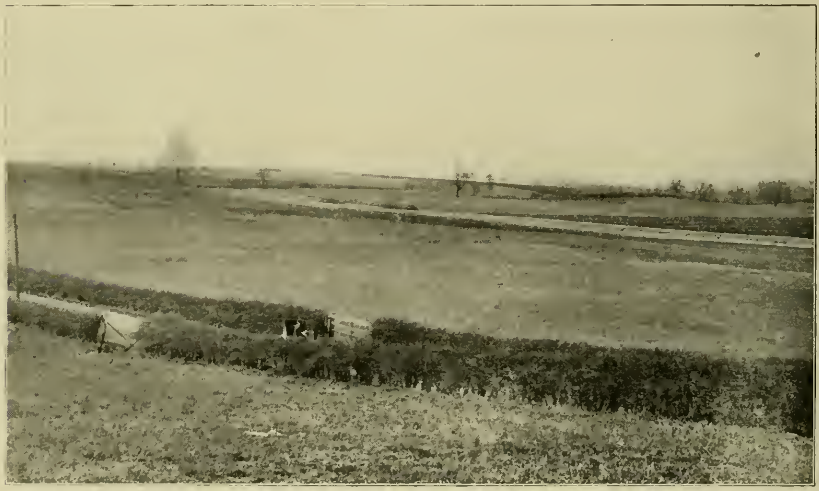

Fig. 2. Looking westward across the outwash plain east of St. Louisville. The drift barrier forms the sky-line.

Along the south front of the barrier, about midway between the rock walls on either side and eighty feet below the highest elevation of the drift, is a well seventy feet deep, entirely in glacial drift. Other well records were obtained, but none were deep enough to establish the maximum thickness of the barrier. As seen in exposures, the drift is made up of gravel, sand and boulders of all sizes imbedded in a matrix of yellow clay; occasionally a large granite boulder is seen, two or three feet in diameter. Scattered throughout the mass of drift are also many fragments of local rock principally of the Logan formation, which had been plucked from the sides of the neighboring valley by the ice.

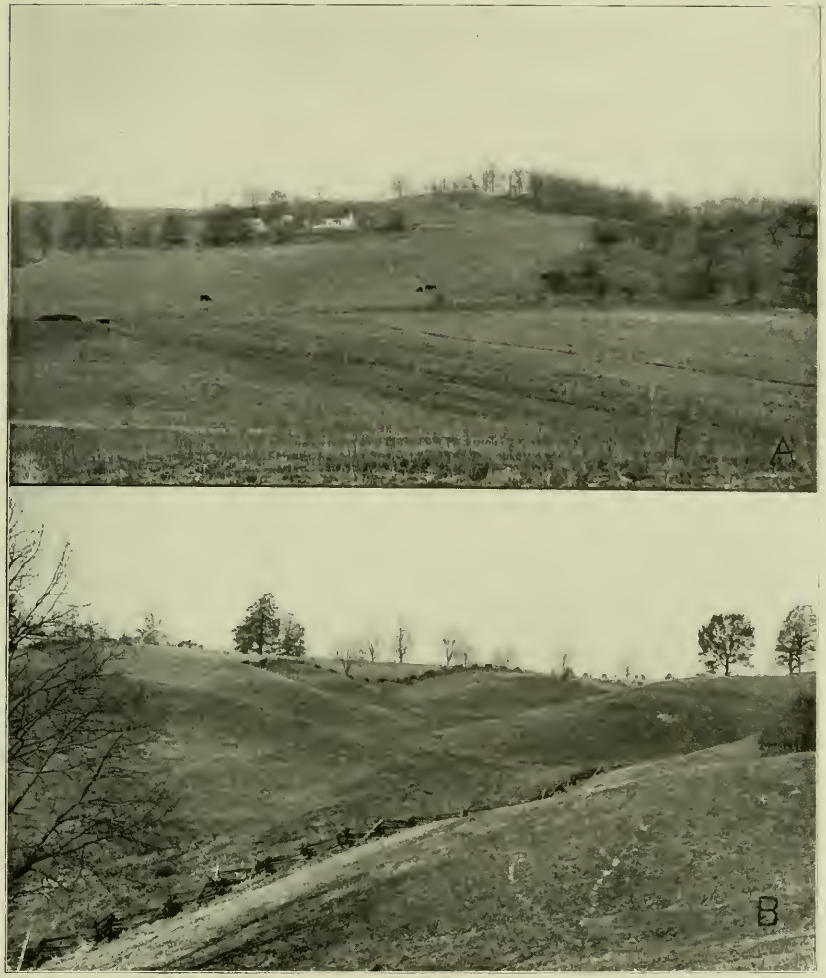

Fig. 3. *A*. Southern slope of the drift barrier east of St. Louisville, *B*. An eroded drift surface a short distance east of the area shown in *A*.

An important feature of this drift is the extent to which it has suffered weathering. Fig. 3, *B*. shows its irregular surface, and the interlocking spurs in one of the many small valleys which have been cut back into the drift. Its age is also indicated by the degree to which the boulders have suffered chemical change; some of the fine-textured crystalline rocks, which would be expected to resist weathering more than the others, on being broken, show an altered band nearly one-half inch wide. These facts indicate a considerable length of time since the drift was deposited. Leverett maps it under Illinoian.[9]

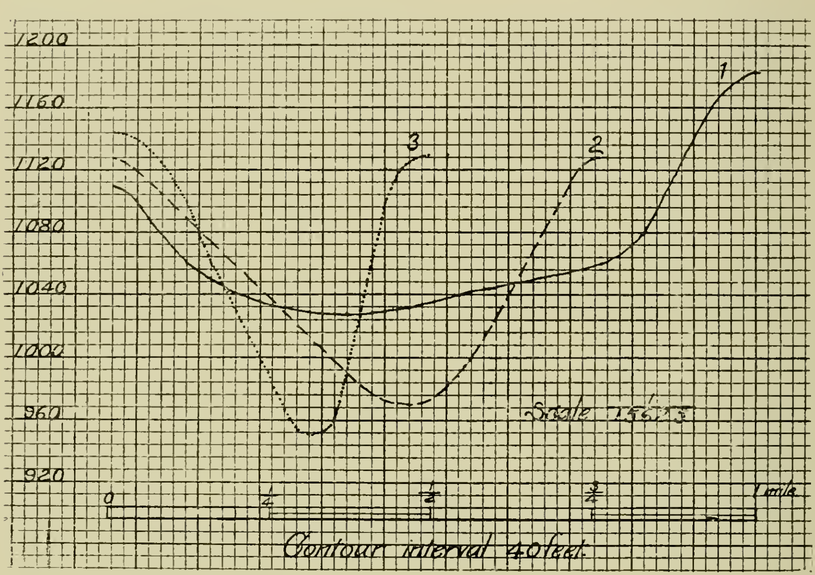

Fig. 4. Cross-sections of the Rocky River valley arranged in down-stream order, 1 to 3; for their location, consult fig. 1.

A possible lake. The glacier standing across this south opening valley must have produced an ice-front lake, if the drainage was then flowing southward. The size of this lake would be determined by the location and altitude of its overflow channel. If the outlet was in segment A, the narrowest part of the valley, over a divide against which Rocky Fork then headed, the lake was deeper than if the outlet was at the west end of part B; under the former condition the lake would have been about twice as large as under the latter; in either case we would expect to find alluvial fans, deltas, lake clay and beaches along the valley walls of the present stream course. Such evidences of a former lake would seem inevitable, considering the great length of time that would be required to change the supposed rock col into the present channel. But no shoreline structures are to be found; therefore it is questioned whether a lake ever stood here.

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[9] *Loc. cit.*, p. 342.

Part C. A swampy condition exists in part C, extending from the margin of the outwash plain northward for about one mile and gradually disappearing. The soil is of a black mucky nature and contains a great deal of vegetable matter. In several places where attempts have been made to dispose of the tall grass by firing it, this black peaty soil has burned to a depth of over a foot. There is no surface evidence of unmodified drift deposits found at any great distance from the margin of the outwash plain. This part of the Rocky Fork Valley has a very low gradient; the farmers have to under-drain the fields to secure sufficient drainage to carry on agriculture.

Another hypothesis. Formerly a stream flowed westward from a divide located in part A; and another stream flowed southward through the present course of the Rocky Fork; this divide is indicated approximately by cross-section 3 (fig. 1). The capture of the headwater section of the west-flowing stream by the Rocky Fork was indicated by differential tilting. A new divide was established in part B; this divide progressed to the west, probably to the position indicated by cross-section 2. This secondary divide probably represents the position which the east-flowing and west-flowing streams held with reference to each other at the time of the Illinoian ice invasion; it is at this stage in their life history that the reversal of part C of the present stream must have taken place. This part of the valley was glacially aggraded in the retreat of the ice to the barrier position east of St. Louisville; outwash deposits tended further to establish a slope towards the secondary divide.

CONCLUSION

This study has attempted to show that this case of stream diversion is due to a combination of causes: first, that of land warping which induced the piracy of part B by the Rocky Fork, pushing the divide back to a position representing approximately the former level of the swamp which occupied part C; second, that the glacier, first by drift deposits left in part C, and later by constructing a drift barrier across its southern end, ponded the stream which flowed into the Licking, and, through outwash deposits, formed a swampy condition, eventually reversing the direction of flow, and adding that stream also to the present Rocky Fork.

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Permanent Secretary Denison Scientific Association

13. The Swasey Observatory, Denison University. By Herbert G. Wilson 347
14. The Contribution of Astronomy to General Culture. By Edwin B. Frost 353

CHAPTERS ON THE GEOGRAPHY OF OHIO

BY FRANK CARNEY

15. The Geologic Development of Ohio 365
16. The Relief Features of Ohio 381
17. Geographic Conditions in the early history of the Ohio country . 403

GRANVILLE, OHIO, JULY, 1911

THE SWASEY OBSERVATORY, DENISON UNIVERSITY[1]

HERBERT C. WILSON

Director Goodsell Observatory of Carleton College

This new observatory was presented to Denison University by Mr. Ambrose Swasey, of Cleveland, and was dedicated on June 15, 1910. At the request of the editor of *Popular Astronomy*, the following information concerning the building and equipment was given by Mr. Swasey and by Mr. T. Milton Dyer, the architect by whom the observatory was designed. Owing to his great modesty, Mr. Swasey does not give much of an idea of the beauty, either of the exterior structure of white marble or the elegant interior finish. The observatory is admirably situated on a high ridge commanding a clear horizon, and is in all respects well adapted to both instruction and research.

In designing this observatory the aim was to produce a building which would adequately meet all the requirements of housing a small telescope with its accessories, and at the same time present an attractive exterior.

The small scale of the building necessitated a simple and flat treatment. The materials selected, both for the interior and exterior, are the most permanent and dignified. The exterior walls of white marble are crowned by a very small cornice, the moldings following classical lines.

The only entrance to the building is through the base of the main observation tower. This leads to a circular room, treated with a Tennessee marble floor, a high Grueby tile wainscot, with plaster walls and cornice above. In the center of the marble floor is a bronze plaque, with a conventional sun in the center and a border formed of the signs of the zodiac (fig. 2).

The walls above the wainscot are painted and over-glazed. A decorative frieze crowns this surface, and contains a running Biblical quotation: "The heavens declare the glory of God, and the firmament showeth His handiwork."

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[1] Reprinted from *Popular Astronomy*, vol. xvii, no. 8, October, 1910.

Directly back of this circular room is a hall giving access to the stairs which lead to the telescope room, the library and transit room, dark room, toilet room and basement.

The transit room has a Tennessee marble floor and a light gray brick wainscot. The plaster walls above are painted in a tone slightly lighter than brick.

The library has a marble floor. The bookcases of oak, fumed, form a wainscot in this room, the plaster above being painted and overglazed in warm colors.

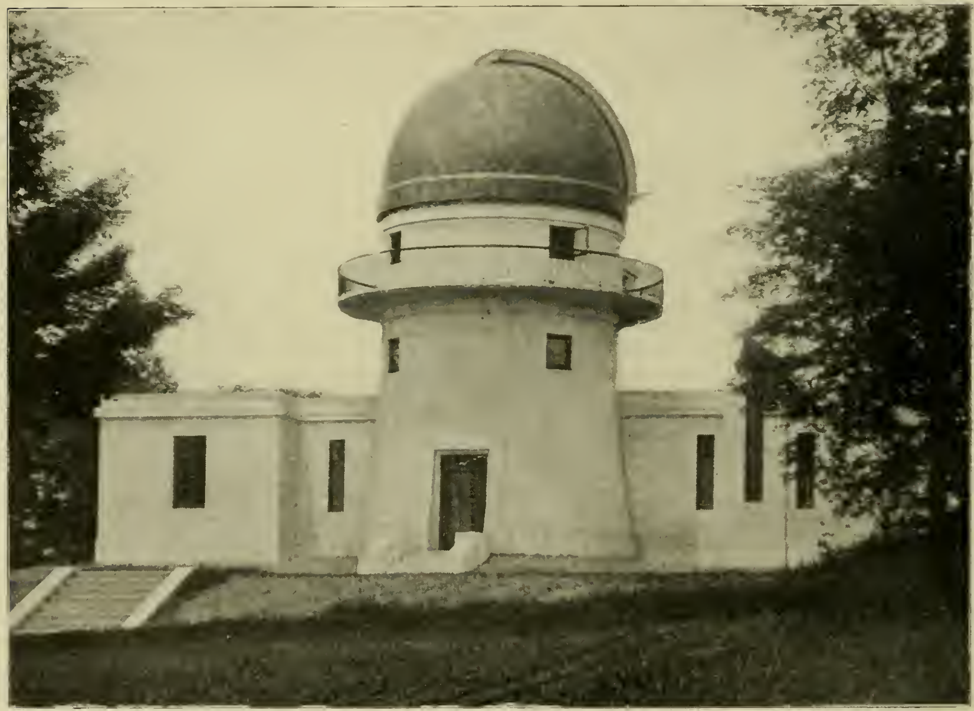

Fig. 1. The Swasey Observatory.

At the level of the telescope room and extending around the exterior of the building, is a gallery with light railing, affording a fine view over the broad valley spreading far below.

The equipment consists of a 9″ equatorial telescope; a 4″ transit and zenith telescope; a cylinder chronograph; two Riefler astronomical clocks; one Seth Thomas clock; switchboard with sounder, and all electrical connections.

The equatorial telescope is one of the standard Warner and Swasey type, similar in design to the 26″ telescope in the United States Naval Observatory, the 36″ Lick and the 40″ Yerkes, and others of similar size designed and constructed by that company.

The column supporting the equatorial head is of cast iron, rectangular in shape, with broad base, extending under the floor at the north side, and mounted on four heavy steel beams which are built into the walls to keep the instrument from contact with the floor.

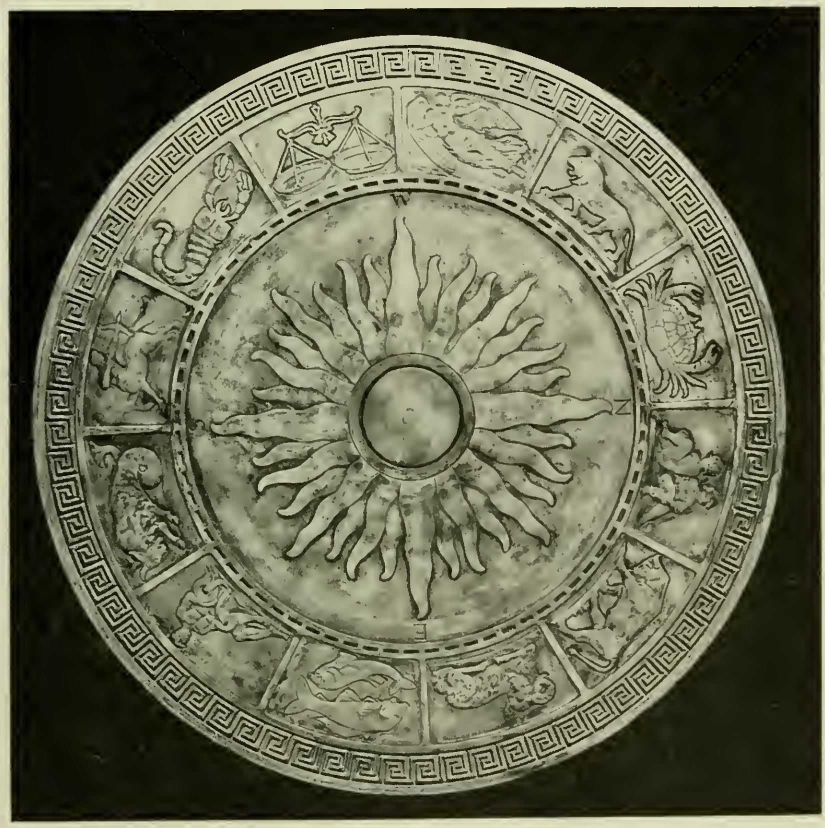

Fig. 2

The upper section of the iron column contains the driving clock, which is protected from dust and injury by plate glass doors. The lower part of the column is utilized for the driving weights which run the clock.

The equatorial head and the bearings for the polar axis are made in one casting. The coarse right ascension and declination circles have large graduations and figures on the face, and are easily read from the floor of the observatory. The fine circles are graduated on sterling silver, and are read by verniers and reading glasses, illumined by small incandescent electric lamps.

The driving clock is of the same pattern as those provided with the larger telescopes above mentioned. It is governed by a double conical pendulum mounted isochronously, making three revolutions per second, and its movement is connected with the polar axis by means of a continuous worm gear having 360 teeth.

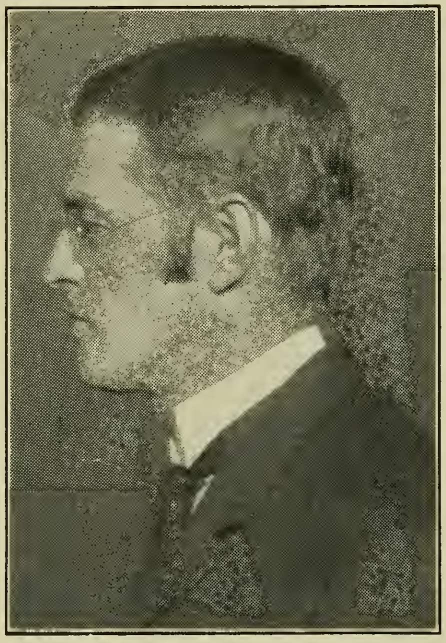

Fig. 3. Edwin Brant Frost, Director of the Yerkes Observatory. The address delivered by Professor Frost at the Dedication of the Swasey Observatory is printed in this number of the Bulletin.

The telescope tube is of sheet steel, very light and rigid. It is provided with right ascension and declination clamps and slow motions, which are governed by handles and knobs within easy reach of the observer. On the north side of the column is placed a dial which is made to revolve in sidereal time by the equatorial driving clock. A double pointer on this dial is made to move in unison with the polar axis, thus enabling the observer to directly point the telescope to the right ascension of the star to be observed, with the same ease that it is set on the declination of the star. Under this sidereal dial on the north side of the column is a wheel with handles, connected with gearing to the polar axis, enabling the observer to easily set the telescope while reading the sidereal dial.

The optical parts of the telescope were all made by the John A. Brashear Company, of Pittsburgh, Pa. The objective has a clear aperture of 9″ and a focal length of 135″; and the finder has a clear aperture of 3″ and a focal length of 17½″.

In addition to the usual number of eye-pieces there is provided a diagonal prism for zenith observations; a helioscope for observing the sun, and a fine micrometer for measuring double stars.

The 4″ combined transit and zenith instrument is of the standard design with iron base and columns. It is provided with a universal micrometer with electric illumination showing dark wires on a bright field. The axis carries two circles 12″ in diameter, one to be used as a setting or finding circle, reading by opposite verniers to single minutes; the other divided upon coin silver with a fine level to read to ten seconds by two double opposite verniers.

The instrument is provided with a most perfect system of reversal, enabling it to be used not only as a transit instrument but as a zenith telescope.

The cylinder chronograph is provided with a driving clock controlled by a conical pendulum similar to that used in the 9″ telescope. It has a drum 7″ in diameter, and 14″ in length, on which is recorded the work done by the transit instrument. A carriage carrying the pen which makes the records is connected electrically with the sidereal clock, thereby making a record on the drum every second. From the same carriage electric wires are carried to the transit instrument, the contact being made by the observer as the star which is being observed crosses the spider lines in the micrometer. By this means a record within one-tenth of a second is permanently made on the sheet of paper carried by the drum. These records of the observer made on the drum during an evening can be computed at leisure by the astronomer.

In the library are two astronomical precision clocks made by Riefler and Munich. These are the finest clocks ever made, their record surpassing in exactness all other clocks. These clocks do not require winding as does an ordinary clock, for they are provided with a series of magnets, which by electric contact wind them every 34 or 38 seconds. A third clock is provided for the transit room, which is of the standard type made by the Seth Thomas Clock Company.

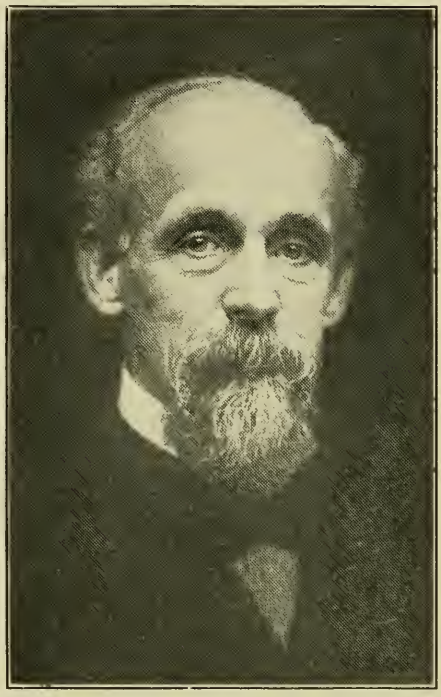

Fig. 4. John Alfred Brashear, Director of the Allegheny Observatory, who gave an address on *Resolutions of the Telescope* at the dedication of the Swasey Observatory.

The address of Doctor Brashear was a very illuminating and interesting discussion of the universe and the means of studying it, a sketch of the gradual progress of man's knowledge of the heavens. The intricate details of observatory equipment were made clear by means of numerous slides, and what has been done with this equipment was fully shown by other slides. The address was a masterful yet simple review of the great field of science to which the speaker has given most of his life.—Editor.

THE CONTRIBUTION OF ASTRONOMY TO GENERAL CULTURE[1]

Edwin B. Frost

Director Yerkes Observatory of the University of Chicago

The word culture may be interpreted in such widely different ways, according to the points of view of different individuals, that its definition might properly be thought to be essential before I proceed with my remarks. I shall forego any such preliminary, however, and hope to use the term in so broad a way that it may include what anyone might mean by its use—learning, knowledge, or the enduring acquaintance with well-thought ideas.

I shall also refer to some of the influences of the study of this ancient branch of learning upon both the teacher and the taught, and the enlargement of mental horizons which its pursuit brings to those who may give much or little of their time to it.

It may be well to approach the matter in a somewhat historical manner, although progress here, as elsewhere, has not been steady, but intermittent, as the genius of some man has illumined here and there the pathway of knowledge. Had one the time for the necessary historical investigation, I believe it would not be difficult to trace the development of this or other branches of learning in such a way that the lives of students should overlap, in point of time, back to the earliest beginnings of recorded history. Thus we could picture the accretions of knowledge, and often of error, as handed on from one worker to another, of very different ability, in very different and perhaps distant lands, and with very unequal value in their separate contributions. Thus the astronomical progress of more than four centuries might be represented in the linkage of the lives of eight men, as follows:

	DIED		DIED
Copernicus	1543	Newton	1727
Apianus	1552	Halley	1742
Tycho	1601	W. Herschel	1822
Galileo	1642	F. G. W. Struve	1864

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[1] Address delivered at the dedication of the Swasey Observatory, June 15, 1910.

It remains to me a singular fact that astronomy should have been one of the oldest of the sciences, even in superstitious ages. We should naturally think in the first place of agriculture meteorology, anatomy and medicine, for instance, as subjects much nearer at hand than star-lore. I am inclined to think that the Chaldean shepherds have been overworked, that their contemplation of the nocturnal skies may have been a secondary rather than a primary concern with them. Is it not possible that we owe as much to the hardy venturers upon uncharted seas, whose course could be set only by the sun and stars, when familiar landmarks of the coast had disappeared from view?

But, whatever the cause, the fact remains that the early philosophy concerned itself with astronomy to a degree which, even an astronomer may admit, was disproportionate to the benefits it was conferring upon humanity. Thales, among the earliest of the Greek philosophers, was seeking for fundamentals and speculating on causes. Both the unchangeable character of the starry skies, and, contrariwise, the variations in them, caused by time and seasons, stimulated speculation. Pythagoras perhaps anticipated by centuries the later knowledge of the rotation and revolution of the earth. With a singular detachment of mind from the immediately practical problems, the ultimate origins and causes were sought. Thus the culture of those ages was deeply impressed by astronomy, as interpreted by the philosophers of each period. With the advent of Hipparchus, the greatest astronomer of antiquity, in the second century before Christ, there was introduced the sound principle of basing the science upon observations, rather than upon general ideas of a speculative nature. How hard his successors have found it to follow in that simple but severe test of theory by fact!

The dignity thus given to our subject by its occupying the attention of some of the strongest intellects of the successive ages was further maintained by the favor with which it was regarded by temporal rulers, by princes of secular and ecclesiastical rank. It is obvious that a clear thinker like Julius Caesar did not have an astronomer near him for reasons of superstition, for astrological interpretations, but because he needed his services in reforming the calendar. In the ninth century, A.D., we find the Caliph of Bagdad, Al-Mamon, son of Haroun el Raschid, preserving to the world the works of Aristotle, Euclid and Ptolemy by causing their translation into Arabic; inaugurating a geodetic survey in Mesopotamia; and founding an active observatory at Bagdad. Albategnius, a prince of Syria, ruler of Damascus, of slightly later date, was a zealous observer, a skilled computer, and introduced improvements in trigonometric methods. Three hundred years later the Mongolian prince, Ilek Khan, founded an observatory in Persia, in which useful observations of the planets were made and the positions of the stars were catalogued. Simultaneously, in Spain, Alfonso X, King of Castile, is furthering the advancement of astronomy, and causes the construction of the so-called Alphonsine tables of the planetary motions. In the fifteenth century, it is a Tartar prince and grandson of Tamerlane, Ulugh Begh, who, a skilled observer, erects a splendidly equipped observatory at Samarcand and catalogues the stars after the lapse of nearly sixteen centuries since Hipparchus. It is perfectly clear that this distinction and interest accorded to astronomy by men of such political and social rank must have greatly tended to the development of public interest in science, with a consequent general culture of the people of the times.

With the advent of Copernicus, (1473-1543), what an immense expansion of mind was prepared for the intellectual world by the substitution of the true heliocentric system for the complicated makeshifts of Ptolemy! Not until after his death did his views receive much attention, but the opposition they aroused in clerical quarters doubless greatly helped to diffuse them. And now came the great explorations of Columbus and his fellow pioneers on trackless oceans. Indeed, astronomy had largely contributed to the general culture of the times, to the grand awakening, the renaissance. Evidence was accumulating to show that comparatively simple laws were governing the complex motions of planets. The careful observations by Tycho and the great generalizations of Kepler were in the logical order of the day. Consider the expansion of ideas, the increase of general culture, which followed the discoveries made by Galileo, as soon as he pointed his perfected telescope toward the moon, the sun, and planets; the existence on the moon of mountains and topography of the general sort of that of the earth; the spots on the ecclesiastically immaculate sun, its rotation on its axis in twenty-five days; the moons of Jupiter and their rapid revolution; the mysterious appendage of Saturn not at first discerned as a ring.

These discoveries, which were merely waiting for the optical power necessary for their revelation, profoundly affected the mental attitude of the intellectual people of the times, when the new knowledge had been diffused. A new place was given to the planets, in their relation to the earth, and a less exalted status in the solar system was the logical consequence for the earth. With its increased, but uncoördinated knowledge, science was awaiting its Newton; but it was almost reluctantly that he gave from his store of knowledge, and we must not forget the great credit due to Edmund Halley for persuading Newton to present the principles he had formulated to the Royal Society. Not only this, but Halley undertook the publication, finally at his own expense (when the coffers of the Royal Society were found to have been drained by other undertakings) of the immortal *Principia* of Newton.

The great impetus thus given to mathematical research, fostered in many cases by monarchs whose other contributions to the uplift of humanity were few, brought brilliant results, and gave the means and methods which led to such a great generalization as that of La Place. We must not forget the earlier and independent philosophizing of Wright of Durham, and of Immanuel Kant of Königsberg. La Place, however, had the mathematical skill and genius to establish many of his conclusions upon a rigid foundation of demonstration. But, in many respects, the generalization of the Nebular Hypothesis outreached observations and mathematical proof. His mind appears to have leaped over barriers which might soberly have been regarded as unsurmountable. He had probably himself hardly seen a spiral, or even a ring nebula. It was beyond the reach of the imagination that men would some day know the chemical constitution of the sun, still less that of the vastly more distant stars and nebulae. But of course the researches of Messier (Louis Fifteenth's "Ferret of Comets") and the splendid investigations of William Herschel, who in 1786 gave to the Royal Society his great catalogue of 1000 nebulae, were available to La Place.

Five years before the publication of the *Systeme du Monde*, which is dated 1796, Herschel, in 1791, had propounded the view that the nebulae differed in nature from the stars. Upon this view he founded his theory of stellar evolution. It has a familiar sound to us now, quite in line with the expanding thought of the last half century. His development of the idea was apparently quite independent of the theory of La Place, which was published between successive papers of Herschel. He early registered his view that the self-luminous matter of the nebulae was "more fit to produce a star by its condensation than to depend on the star for its existence." He arranged in an orderly series the different objects he had discovered and found "perhaps not so much difference as would be in an annual description of the human figure, were it given from the birth of a child till he comes to be a man in his prime." This reference to the evolution theory of Herschel is made here as a matter of justice; but he is far better known by his many observational discoveries than by his speculation, while La Place is doubtless better known for his Nebular Hypothesis than for his splendid work, the *Mecanique Celeste.*

The impress of the hypothesis of La Place upon the culture of the nineteenth century has been profound. What collegian has escaped the grandeur of the conception of so complicated a result as our solar system developing under comparatively simple laws? To have this conception brought distinctly to the attention of the student is, to my thinking, almost argument enough for making astronomy a required study in college.

Here let me answer in advance the question often asked of the practical astronomer or astrophysicist: Is the hypothesis of La Place now obsolete, and discarded, or supplanted by views better in accord with modern research? My answer would be in the negative, and I know that this view is shared by many of my friends whose opinion I value. It is true that this theory of La Place is inadequate in some respects, and is mathematically unfounded in some particulars. Its premises need modification, and it also leaves much unexplained. But no adequate substitute has been proposed, and the increased study of the different phases of development, as inferred from stellar spectra, supports the La Placean theory surprisingly.

Let us pass to another of the great scientific discoveries of the nineteenth century, crystallizing in the decade when *The Origin of Species* appeared. I refer to the interpretation of celestial spectra. From the beginning of the century, the existence of dark lines in the solar spectrum had been known, and as early as 1817 Fraunhofer had examined with the prism the light from some of the stars and planets. The double dark line in the solar spectrum (known as D) was known to coincide closely with the bright line in the spectrum of the sodium flame. Stokes, Balfour, Stewart, Foucault, had all groped near to the truth. It was Kirchhoff, whose researches were made in connection with the eminent chemist, Robert Bunsen, who announced in a communication to the Berlin Academy of Sciences, in 1859, the correct interpretation of the dark lines in the spectrum of sun or star: they show the presence of an envelope of glowing vapors around the star.

Here, again, a tremendous expansion was instantly given to the horizon of thinking people. But to astronomers it was undoubtedly a far more impressive discovery, for it was the key to open the door to indefinite new realms of knowledge. Hereafter the position of a heavenly body and its motions were not to be the sole objects of inquiry, but their physical and chemical nature were to be investigated. And one of the special features of the discovery was that the spectroscope suffered no limitations from distance: provided the light was bright enough for analysis, the most distant star could be as well investigated as the nearest. This is of immense advantage, for in practically all investigations which depend upon angular motion (across the face of the sky) the errors of a determination increase proportionately with the distance from the earth.

A wide field for research was opened up by this discovery, and the branch of astronomy known as astrophysics began its remarkable development. The spectroscopic study of all celestial objects was promptly undertaken: in 1864 Dr. William Huggins examined the spectra of a nebula, the bright planetary nebula in Draco. To his surprise, he saw no band of color, the radiation was chiefly monochromatic; the nebula was gaseous. The statement sounds so simple that we lose its immense significance: Here was the first verification of the visions of Herschel and of La Place: they could have had no thought that it would ever be possible to determine the physical state and chemical constitution of the nebulae: even the discoverer, Dr. Huggins, was at the time surprised—he had not suspected the simple result. This was one of the many pioneer discoveries of this fine modern example of a genuine old master of his science, the grand old man of astrophysics, whose death last month, at the age of eighty-six, in the fullness of his mental powers, is lamented by all astronomers. By this particular discovery he showed not only that the nebula was gaseous, but also that it contained the omnipresent hydrogen, in addition to an element for which a corresponding line has not yet been found on earth, and for which element the name nebulum has been adopted.

With the name of Huggins are associated many of the revelations of the spectroscope, made during more than four decades. Zöllner, Secchi, Lockyer, Janssen, Young, and Langley were among his most distinguished contemporaries in astrophysics, and had a worthy share in the rapid progress then making.

Without here discussing the relative value or amount of the contributions of these leaders, we may say that with the name of Huggins will always be connected the correct theory of the visibility of solar prominences, the first application of the principle of Doppler and Fizeau to the measurement with the spectroscope of the speed of the stars in the line of sight, and the successful development of the photography of stellar and nebular spectra. His discussion of the different types of spectra and of their probable order in celestial evolution is characterized by a sane judgment and clear exposition. It is a duty as well as a pleasure to refer publicly to the debt which astrophysicists owe to our deceased master.

This brings us to another of the great principles revealed by the continued celestial application of the spectroscope and spectrograph, namely, that of the qualitative unity of the universe. Such ideas as this, when properly impressed in the literature of science, cannot fail to affect markedly our conception of the universe, and our relation to it, and thus to contribute to the world's culture. I cannot feel that the idea has ever been sufficiently emphasized in popular writings or teachings. In essence, it is this: Despite the immense quantitative range in the universe, from the infinitesimal to the almost infinitely large, in mass, in space, and in time; qualitatively the range is very narrow, and our sun, our earth, our very bodies, very fairly represent the whole range of quality in the universe. The chemical elements with which we are familiar, which form the basis of our experience on earth, or are spectroscopically obvious in the sun, are essentially the same in the most distant star.

In a universe whose spatial depths are not sounded even by thousands of millions of millions of miles, populated by millions, (perhaps thousands of millions) of vast objects, why should there not be thousands or millions of kinds of matter—chemical elements by the millions? I see no answer but the fact that there are not, so far as terrestrial or celestial chemistry can yet ascertain. In a century's progress in chemistry, the number of elements detected and differentiated is less than one hundred; and the outlook, as I, without any technical knowledge, understand it, is toward a decrease rather than an increase of the number of elements. And it is just those very elements with which we are most closely associated in our bodies and in our surroundings that particularly abound in the far reaches of space: hydrogen is present, less than half a dozen stars excepted, in every star and gaseous nebula in the heavens; oxygen, nitrogen, silicon, carbon, magnesium, sodium—the most familiar elements of our atmosphere and the earth's crust—are conspicuous in the spectra of stars, both early and late in the course of stellar evolution. Helium, so recently discovered in the earth, after being known to astronomers as present in the sun for the quarter of a century previously, also plays an especially important part in the chemistry of one of the most interesting types of stars, being the chief characteristic of the stars of the *Orion* type. There is one form of hydrogen which chemists have not yet produced in the laboratory, although the keen analysis of Professor E. C. Pickering established its existence in a few special stars a decade ago. Nebulum, too, will presumably be found within the earth, perhaps occluded in some crystals yet to be found into which it may have been absorbed (like helium) ages ago.

This consideration of the homogeneity of the universe offers us some genuine consolation, when we have been depressed by reflections on the immensity of the universe and the utter insignificance of our earth, or our solar system. We may proudly remember that, nevertheless, in quality, which is perhaps a far more essential matter, we share in the choicest of the whole universe. It is a tempting speculation to infer that, if matter does not differ widely in quality in the universe, mind, too, in its relation to matter, is not subject to an extensive range. No logical person can believe that the conditions for the mutual existence of mind and matter solely exist on this particular planet of this particular star, which we call the sun. Hence we could guess that the sentient beings on other spheres of space would not differ so utterly from ourselves. But such speculations can scarcely ever be subject to the test of experiment or observation, and may not be soberly pursued further.

The eminent evolutionist, Alfred Russel Wallace, a contemporary and friend of Darwin, and justly entitled to share with him in the credit for introducing into science the great principle of evolution, has recently, in his old age, written a book, entitled *Man's Place in the Universe.* Basing his discussion upon the premise that our sun is near the center of the Milky Way, he argues at great length and with much erudition (particularly for a biologist essaying in a new field) that the earth is the only habitable planet of this or any system, and "that the nearly central position of our sun is probably a permanent one and has been specially favorable, perhaps absolutely essential, to life development on the earth." The book seems a singular contradiction to the previous work of its distinguished author; in politics it would be called "reactionary." Even if his evidence and arguments were convincing, which they are not to practical astronomers, his conclusions would be narrowing and restrictive. It appears to me a splendid thought that, with our feeble intellects bound down to frail bodies, on a pitiful little planet of a mediocre star, our humanity is able to accomplish so much, see so far, and dream such great dreams. We may share with Dr. Wallace in his appreciation of the following lines from Tennyson, but without excluding from our philosophy the possible coexistence of millions of other abodes of mind and matter.

The Question

Will my tiny spark of being
    Wholly vanish in your deeps and heights?
Must my day be dark by reason,
    O ye Heavens, of your boundless nights,
Rush of Suns and roll of systems,
    And your fiery clash of meteorites?

The Answer

"Spirit, nearing yon dark portal
    At the limit of thy human state,
Fear not thou the hidden purpose
    Of that Power which alone is great,
Nor the myriad world, His shadow,
    Nor the silent Opener of the Gate."

It is characteristic of the audacity of the human mind that it can pause nowhere in a research once begun; finality is never reached; but new avenues of approach toward an apparent solution are constantly opening.

During the few hours I have spent at this University, I have noted, and with satisfaction, the distinctly religious tone of the institution. Let no one fear any ill effect upon a reverential mind from the pursuit of the science that reaches out to the very frontiers of the Universe. The study of astronomy is foremost in demanding the recognition of a Creator greater than all of His vast creation.

The battleground of modern practical astronomy is shifting, out to the problem of the structure of the sidereal universe. The first Herschel attacked the problem, and by his observations laid a foundation for later work. The question of great interest now is, Whither? The genius of the eminent Dutch astronomer, Kapteyn, has detected law in the apparently random residual motions of the fixed stars. Dealing with stars, not singly but in great groups, he has found evidences of what he has called "star streaming." The study began with the determination of the sun's way, the path along which the sun is hurrying, carrying with him his unconscious planets, toward the region between the constellations Hercules and Lyra. Other astronomers confirm the conclusions of Kapteyn that there are in the sidereal universe at least two great streams of stars, and that they cross each other and mingle at some points. Such a problem is so vast, and the data required are so extensive, that it transcends the capacity of the astronomers of one country. Like many other large practical problems, as for instance the great star catalogue of the *Astronomischen Gesellschaft*, or the great photographic chart and catalogue of the whole heavens, such undertakings have to be international. Conferences, charming in their generous hospitality and fraternal courtesy, are now being often held in different countries. The International Solar Union, for the coöperative study of the sun and its phenomena, meets this year at Pasadena. Such gatherings, becoming frequent in many other branches of science and art, are quietly but powerfully contributing to the cause of international peace. Continued and developed, they will operate effectively against the crowning absurdity of our age, the huge armaments of the great powers. If the productive power of the men thus withdrawn from useful activity could be utilized, and the vast sums of money wasted on unnecessary ships could be spent on submerged humanity, how immense would be the gain to civilization!

In celebrating to-day the opening of the beautiful observatory which will hereafter develop in this institution the science which has been my theme, it is fitting that we should briefly consider the advantages to student and teacher of the study of astronomy, both general and practical. The eminent classical authority, Professor Mahaffy, once told me that at Trinity College, Dublin, there were but two required subjects in the curriculum: logic and astronomy; and he justified this choice. It is surely true that no other subject of college instruction so instantly or so greatly broadens the horizon of the pupil. It is likely to catch the imagination and interest as few other topics do, and particularly when an observatory is at hand, where celestial objects and their phenomena may be demonstrated to all the members of a class. The vision of the planet Saturn or of a fine star cluster, in a good telescope, is likely to produce an impression that time will hardly efface. As a foundation for geology, geography and meteorology, and as affording constant applications of principles previously learned in mathematics, physics and chemistry, astronomy has a particularly important place in the college curriculum. Mere familiarity with the principal constellations, once acquired in connection with a course in astronomy, will always prove a pleasure to its possessor, perhaps increasingly so in later life. The understanding of the general facts of planetary motion, as of the changes from evening to morning star, is also likely to be a permanent source of satisfaction.

The pursuit of courses of practical astronomy in an observatory is essential to the education of an engineer, and very desirable for those specializing in the physical sciences. The art of determining the time and the observer's position on earth from observations of the stars, gives the student who acquires it a certain self-reliance that is of lasting value to him. The accuracy necessary in all computations involved in the reduction of his observations gives an exceptionally good drill in applied mathematics. The principle that no observation made by the human eye is absolutely precise, and that no instrument is ever in perfect adjustment, and that these errors must be determined and allowed for—this principle is of obvious use in the training of any student for precision in any future work.

Courses or studies in astrophysics, such as observing, measuring and following the motions and changes of sun-spots, examining with the spectroscope the fascinating solar prominences and eruptions, measuring the brightness of the stars, determining the changes in light of the variable stars—all these commonly prove of much interest to the pupil, and stimulate him to the closer observation of nature.

To the teacher, also, the observatory is no less important than to the student. Here he gets information at first hand, notes with his own eye phenomena he had only dimly understood from descriptions in text-books. His enthusiasm for his work is likely to be greatly increased by the opportunity to see for himself, and to show to his pupils the phenomena. With as well-equipped an observatory as yours, the teacher can, if his time permits, also make real contributions to science, and no man can make such researches, modest though they may be, without gaining new enthusiasm for his work as teacher, and without imparting this interest to his pupils.

In congratulating the University on this admirable addition to its equipment, the value of which we have imperfectly expressed, permit me also to congratulate the generous donor upon the excellent adaptation of the gift to the purposes of the University. That the instruments are as perfect as they can be made, is obvious to all who know the man and the work of the firm which he and his excellent partner have made famous. This observatory will be a lasting evidence of his affection for the University and of his interest in the ancient branch of science, the achievements of which will be more interestingly presented by my friend, the speaker of the evening. And this observatory will not be the only monument to the donor, for the succession of astronomers who are so fortunate as to work with the two great masterpieces of the genius and skill of Warner and Swasey will not fail to bear testimony to their continued appreciation of the perfection of these indispensable instruments of their research.

THE GEOLOGIC DEVELOPMENT OF OHIO

Frank Carney

Introduction 365
    Geologic time
    River sediments
    Ocean sediments
The origin of rocks 368
    Nebular hypothesis
    Planetesimal hypothesis
    Age of weathering processes
    First stage in rock-making
    Metamorphism
    Clastic and organic rocks
    Rocks precipitated from solution
The growth of land areas 373
    The Cincinnati arch
    The Appalachian mountain-making movement
    The Allegheny plateau
    Relief and glaciation
Periods of geologic time represented in Ohio 376
In general on geologic processes 379

INTRODUCTION

The surface features of any region pertain to its geography; the underlying rocks contain its geology, and embody a composite of its past geographies. To-day's geography, then, will become a page in the geology of the future.

Geologic time. That the rocks may be analytically studied, men have grouped them into eras and smaller divisions. The basis on which the rocks have been thus classified is chiefly their content of fossils, though geographic changes are important. The oldest rocks are said to be without organisms; from that early era to the present, the gradual development of species, and the gradual increase in biologic complexity, has led to the naming of the succeeding eras. The better known eras are divided into periods, representing either a striking difference in their fauna, or an unconformable relationship to the strata of the preceding period:

ERAS	PERIODS
Cenozoic	Present
	Pleistocene
	Pliocene
	Miocene
	Oligocene
	Eocene
Mesozoic	Cretaceous (Upper Cretaceous)
	Comanchean (Lower Cretaceous)
	Jurassic
	Triassic
Paleozoic	Permian
	Pennsylvanian
	Mississippian
	Devonian
	Silurian
	Ordovician
	Cambrian
Proterozoic	Keweenawan
	Upper Huronian (or Animikean)
	Middle Huronian
	Lower Huronian
Archeozoic	Archean

The consolidated rocks of Ohio belong entirely to the Paleozoic era; resting upon these, is much unconsolidated rock material belonging to the Pleistocene and Present periods of the Cenozoic era. We have, then, no rocks that are geologically very old, nor have we the hard and resistant rocks. The formations of the earlier periods have undergone changes that make them less easily disintegrated by agencies of weathering; they are uniformly more dense than younger rocks. The formations of the early eras are usually crystalline in structure, whereas sedimentary rocks characterize the later eras. It is not improbable that many of the crystalline rocks were originally sedimentary.

River sediments. Since the rocks of Ohio are sedimentary, it follows that they had their origin in the assembling of the weathered products of older rocks. The rivers that to-day carry off the products of weathering are depositing these products along their courses and in the oceans; such deposits will in time form sedimentary rocks.

Where were the land areas whose streams bore the sediments from which were built the series of rocks within this state? Obviously much of the sedimentary rock material of Ohio was transported here by drainage from older lands to the north, while some may have been deposited by streams flowing westward from lands that existed farther east. While the rocks of our state were accumulating, the ocean occupied the region of the present Mississippi valley; the Ohio area, during most of the time, was a portion of this interior sea, but later it was a gulf or bay extending northeastward.

The same agencies were active in forming the sedimentary rocks in the Ohio scale as are in operation at the present time. Along the rivers material is in transit. Some of this load is always on the move; some is carried on in installments, a period of rest following one of movement. The part of the load that reaches the large bodies of water, a lake or the ocean, is the finest; this is largely deposited near the mouth of the river as a delta. In time the delta grows more and more into the body of water, forming a wider marsh region. But a very significant part of stream deposits is found in the flood plain that borders the river channel from the sea inland; in the flood plain of any mature river we can see ample deposits, enough to make hundreds of deltas such as exist at the river's mouth. As the major river widens its valley, the tributaries also become bordered by deep deposits which they are unable to carry onward.

So a river's history is one of constant work, and of various kinds of work. At some particular point along the river's course, it is doing such work as at an earlier time it did farther down stream. Rivers first cut into the rock, deeper and deeper; later they cut laterally, making the valley wider. But while they are engaged down stream in widening a valley, upstream their business is deepening the valley. So long as the stream is cutting deeper, it generally carries away the products of this erosion; when the work changes to valley-widening, it fails to carry off all of the products of its erosion; thus flood plains are made.

An old valley need not be of great length in order to have several hundred square miles of flood plain deposits; the Mississippi southward from Cairo, Illinois, is an example. A large percentage of the surface of a region that contains several old streams consists of flood plains. Much of this flood plain material in a later period is changed to consolidated rock without ever being carried to the seas. There was a time when students thought the sedimentary rocks all represented material that had been deposited in, or near, the oceans.

Ocean sediments. On the other hand, ocean waves and currents are contemporaneously engaged in eroding the rock along parts of their borders, and in further refining the river deposits. Thus the oceans may be constantly sawing into the continents, pushing their cliffs gradually inland, thus contributing materials for sedimentary rocks of the future. The waves undercut the cliffs, pound up and prepare a load which the ocean currents carry away, assort, and deposit. Our seashores then are another belt where sedimentary rocks are in-the-making. Nevertheless a conspicuous part of the sedimentary rocks are associated directly with river basins.

But how may we so distinguish the rocks of the past that we may be sure which of them represent old seashores and which flood plains? It is not an impossible task. Careful study has been made of the prolific life of the ocean border tract, and the sometimes equally abundant life of the river flood plains. These faunas in the main are quite distinct: on the one hand marine, on the other, fresh water. When the animal dies its tissue is sometimes replaced by minerals, producing a fossil. In the fossil form these organisms may be studied and classified. Therefore it is usually possible to tell whether a certain horizon of rock represents fresh water or marine sedimentation.

THE ORIGIN OF ROCKS

Old ideas as to the origin of rocks have been somewhat modified in recent years, because of new teachings of astronomers and physicists in reference to the origin of the earth itself. There are two more widely accepted hypotheses of earth-origin. I will state briefly the parts of each which bear more directly on the genesis of rocks.

Nebular Hypothesis. The early conception of our globe pictured its gradual evolution from a spheroid of gas which slowly condensed, acquiring great heat, and forming at last a molten body about the size of the present earth. As heat was radiated from the surface of this hot spheroid, a cool crust developed;

with the radiation of further heat, this crust shriveled about the contracting center. In this manner mountains were made. Later, with the appearance of an atmosphere and hydrosphere, the agents of weathering with which we are acquainted became operative.

Since the earliest rocks formed were considered frozen or cooled molten material, they were called plutonic rocks. So the basal formations, according to this theory, were looked upon as igneous; and the later weathering of the igneous rocks produced material that formed the sedimentary horizons. This is the Nebular theory of earth-origin, omitting, of course, all details that concern the origin of other members of our planetary system.[1]

Astronomers of the present generation have made wonderful discoveries; their predecessors had neither such powerful telescopes, nor the other observatory equipment with which the modern astronomer does his work. The marvelous facts of the heavens revealed by the great observatories in recent times have caused doubts concerning the time-honored Nebular hypothesis, which had its origin in very incomplete data at a time when observations and calculations could not be accurately made.

Planetesimal hypothesis. Quite opposed to this, is a theory which has been formulated within the last decade. In accordance with this hypothesis our earth has not always been a contracting body; it was not a molten mass to start with, but instead a gradually increasing sphere possessing a moderate degree of heat. This theory conceives our planetary system as having evolved from a nebulous body like the present nebulas, the units of which are called planetesimals. The large modern telescopes show the prevailing form of nebula to be disc-like, not spheroidal, in outline, and to be spiral in structure; to have a denser center from which generally two arms extend giving the nebula its spiral structure, and to have apparent motion about this center; furthermore, there appear dense masses or nuclei along the arms, and in the interval between the nuclei, as well as between the arms, "finely divided and nebulous material."

In their revolution about the center, it has been suggested, the orbits cross and collisions between planetesimals take place, forming larger particles. The orbits of single and combined planetesimals cross or pass near the orbits of nuclei, whereupon the smaller bodies unite with the larger. By this accretion process bodies are formed which dominate a certain amount of space from their centers. These growing masses through further accretions became initial planets. Some of these may unite with others, but eventually the members of our present solar system were formed.

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[1] For a full discussion, see Moulton's *Introduction to Astronomy*, pp. 440-447, 1907.

But we are concerned with neither hypothesis any further than the aid it offers in understanding the origin of rocks; both accord in the principle that sedimentary rocks contain the weathered products of older rocks.

Age of weathering processes. The Nebular hypothesis, however, gives us only a limited zone of secondary rocks, while the Planetesimal teaches that secondary rocks were in process of formation from a time when the earth was but a fraction of its present size. In the various processes of weathering, water and certain chemicals are the essential factors. But there was a time, it is thought, when the earth was not surrounded by an atmosphere, and its surface bore no hydrosphere. In the absence, then, of these two spheres, it is probable that the original rock suffered very little change, certainly not all the changes which we know of as weathering. An atmosphere is matter in the gaseous form. Only when a planet becomes large enough to exert sufficient gravity to hold gaseous matter near its surface, will it have an atmosphere; for this reason, the early atmosphere of a growing planet consists of the heavier gases.

The moon has no atmosphere; hence we believe that the gravitative power of the moon is not sufficient to control hydrogen, oxygen and other gases. We are also told that Mars, which is about one-tenth the size of our earth, has a very slight atmosphere. From this fact we infer that Mars is large enough to control some gases. If the analogy of these two members of our solar system may be used in interpreting the theoretical history of the earth, it must be concluded that the earth has been surrounded with at least a slight atmosphere from the time it was about one-tenth its present size. The surface of the moon appears not to have a hydrosphere. Whether Mars has any water on its surface, is a mooted point. Theoretically, however, we would infer that a growing planet should have a gaseous envelope before the depressions on its surface would be filled with water. If water appears before the atmosphere, we might thus account for an atmosphere, because hydrogen and oxygen in the water molecules are readily vaporized, and should, if present, give the growing planet a gaseous envelope in the form of vapor.

Accepting the teachings of the Planetesimal hypothesis, it is safe to conclude that the agents of weathering have been operating on this planet at least from the time it was much less than one-half its present size. The earth was growing apace, through accessions of unattached bodies from the original nebulous matter. Thus during the time that the globe has been making at least half its growth there has been a mingling of new material from without and the weathered products of old material. But the amount of the accessions has progressively decreased; since the beginning of what is generally called "geologic time," the Archeozoic era, the accretions are relatively negligible. Nevertheless every meteorite that occasionally falls adds something to the earth's mass.

Weathering is the agent that rends old rocks and produces new ones. Freezing effects, the expansion of higher temperatures, and certain chemical changes cause disintegration; stream and wind erosion, and later transportation of the weathered products to lower altitudes and into water bodies are details in the change from original to secondary rocks.

First stage in rock-making. You have seen cemented masses of clay, gravel, large and small stones, and possibly also organic material, which had been bound together by a deposit of carbonates, of iron, or of silica, precipitated from ground waters seeping through the masses? This is an early step in the development of sedimentary rocks. In accordance with the coarseness of the material thus cemented, the rock produced is termed a conglomerate, a sandstone, or a shale. Later other sediments may be deposited on top, the weight of which tends to further indurate the lower sediments. Pressure also arises from the movements of uplift and depression incident to the development of land areas. These movements are sometimes extensive, folding the rocks, or even stretching them throughout large areas. Such mechânical action produces heat which is considered a very active agent in altering rocks. Thus, an original mass of loose sand, or of coarse and fine gravel, in time will become a sandstone or a conglomerate, and under further action of the same agents may later be changed to rocks that are quite unlike the original.

Metamorphism. Geologic time is involved in these processes. The time units of human beings give us but a slight conception of geologic time. The process that changes rocks into quite different rocks is called metamorphism. Metamorphism, it is thought, has altered all rocks appreciably, save those of the most recent period of earth-history. Metamorphic agencies have been so effective in changing some rocks that it is very difficult to tell what may have been their original form.

When we recall that man sees only the upper part of the earth's rocks, never getting a view of more than a few miles below the surface even when he combines numerous outcrops widely separated, we begin to comprehend the limitations in his study of rocks. These limitations have led to his setting up standards of earth-history, implying an equally short period during which the agents that have produced secondary rocks have been operating. His not comprehending the extent of metamorphism has also led to his interpreting the older crystalline rocks as primitive or "plutonic." According to later views many rocks of the Archeozoic may be altered sedimentary strata.

The effects of metamorphism are variable. Sometimes a familiar rock blends into its metamorphosed product. For example, marble, which is an altered limestone, may be quarried in a locality, on either side of which, within a distance of a few miles, the marble gives place to limestone. Again, an outcrop of quartzite, traced laterally, may blend into unaltered sandstone.

That heat is an important factor in metamorphism, we are certain, because near the line of contact between a dike of igneous rock and the formation it cuts, the strata are changed, whereas a short distance from the contact, they are unaltered. A flow of lava coming in contact with a bed of bituminous coal may change it to anthracite. Many other illustrations might be cited, showing the effects of heat, pressure, water, and chemical agencies in altering rock.

Clastic and organic rocks. The sedimentary rocks formed by assembling worn out products of older rocks are called *clastic*. The great bulk of our secondary strata belong to this division. Not all the load which rivers carry from the higher areas to their flood plains and into the ocean is deposited, and later turned into secondary rock. Many of the constituents of older strata are broken up into their chemical elements, and as such enter the oceans. Because of this fact, ocean water is salty and heavier than fresh water. We sometimes speak of the saltiness of the sea, usually referring to sodium chlorid. But this is a single chemical; all the list of chemicals found in rocks exists in sea water. Certain animals in the oceans feed upon particular chemicals. The carbonates, and to some extent the silicates, are converted into the hard parts of sea organisms. When these organisms die, their shells, spines, etc., are assembled at the bottom, and when especially numerous make characteristic deposits; becoming rock, these are named in accordance with their prevailing constituent. If the animal's remains consist largely of carbonates, the resulting rock is called a limestone; if the clayey or sandy content is conspicuous, it may be called a calcareous shale or sandstone. In the deeper parts of the seas, however, smaller organisms exist, and their remains become a part of the ooze that mantles the bottom of the ocean basins. Rocks which are built up largely of the decayed products of life are called *organic*.

Rocks precipitated from solution. Sometimes the percentage of a given chemical becomes so high in water that it is precipitated, depositing on the bottom of the basin that particular salt. It may be a gypsum deposit, a sodium chlorid deposit, or some carbonate. This process of direct precipitation is usually associated with arid conditions in an inland drainage basin. Here the evaporation is greater than the rainfall; as a result, the amount of chemicals in the water is constantly increasing. When, for a particular compound, the saturation point is reached, it is precipitated. Later the solution may become saturated for another compound, which in turn is deposited.

The remarkable salt deposits in Ohio belong to this class of rocks. Their genesis, however, may not be associated with inland drainage; this question is discussed in an earlier section (p. 152).

THE GROWTH OF LAND AREAS

The geologic scale of Ohio includes clastic, organic, and chemical rocks. We have no crystallines, and no metamorphosed rocks in place; but scattered over the surface throughout at least half of the state are found bowlders of crystalline and metamorphosed material brought from Canada by the glaciers.

For many miles off the eastern coast of the southern Atlantic States the ocean is very shallow. A relatively slight upward movement of this part of the continent, or a corresponding withdrawal of the ocean, would add to the area of North America. This added belt would be called a "coastal plain." Continents often grow thus, taking from the shallower parts of the oceans.

The Cincinnati arch. Towards the close of the Paleozoic era the sea withdrew finally from the region of Ohio. Before that time, only a small part of the state's area was above sea-level; in the southwestern corner, about Cincinnati, is the oldest land in Ohio. Long before the close of the Paleozoic era, a dynamic movement gradually produced an arch, raising from the surrounding sea a long peninsula-like strip. This has been termed by students the "Cincinnati arch," and it is very typical of the orographic movements associated with the growth of continents.

Just why certain areas near the continent borders are moved differentially, or bent into arches, is not clear. Some hold that it is due to the unequal distribution of sediment from the contiguous lands. If the products of disintegration were evenly spread into the oceans, it is urged, we would not have the irregular oscillations, but where a narrow tract is thus overloaded the rocks beneath are compressed accordingly and an arching of neighboring rocks is produced. When two such overloaded areas are not far apart, the intervening belt may be bent upward, as illustrated in the Cincinnati area.

Students determine the approximate time when such a movement occurred by a study of the rocks involved. In the case at hand the disturbed rocks show a maximum movement near the southwest corner of the state, only diminishing northward; one effect of this arching and the resultant stream erosion may be seen today in the scattered limestone islands about Sandusky. The strata dip downward on either side of the axis of this uplift. Along the axis the older rocks are found nearer the surface. Furthermore, along this axis weathering and stream erosion have been most active; also the last sediments deposited before the movement began are uppermost, and dip either way from the axis. Since along the borders of this arched area, the rocks are much younger than any found on its top, it is inferred that the arching commenced before these younger sediments were deposited. Accordingly, the beginning of the uplift movement has been definitely associated with the latter part of the Ordovician period.

Appalachian mountain-making movement. For a long time after the development of the Cincinnati arch, the Ohio region was almost continuously a part of the sea. In addition to the arched area, lands exposed to weathering existed to the north, and farther away to the east. From these sources, products of weathering were being transported, gradually making more and more shallow the sea over this region. The great dynamic movement that produced the Appalachian mountains commenced in the Permian, the closing period of the Paleozoic era. This folding probably began in the eastern section of the northern Appalachians, proceeding westward and southward. The youngest sediments found in Ohio belong to the Permian. It is possible that sedimentation may have continued after that period in parts of our area; if so, such deposits have been completely removed, or have never been located by geologists.

Since the Permian, then, the normal agents of weathering, which we see all about us to-day, have been acting on the rocks of our state, sometimes subdued, at others vigorous. At intervals the rivers have been building flood plains, as their velocities lessened; again, because of a differential movement, or because of an uplift, the invigorated streams commenced to erode their beds and carry away waste products. Later, all these processes were checked in about half the area of Ohio by a sheet of ice (p. 185).

The Allegheny plateau. The western slope of the Allegheny plateau extends diagonally across the state from northeast to southwest. This plateau, ranging in altitude up to thirteen or fourteen hundred feet, is genetically associated with the same movement that produced the Appalachian mountains. The Ohio river and its tributaries have in a measure severed this part of the uplifted region from the more elevated section to the east; the Scioto, of its several tributaries, occupies the greatest gap in the plateau. Not only is this section elevated, but closer study of the rock structures betrays many folds and flexures also, consisting of slight anticlines and synclines. The rocks concerned have a prevailing dip to the south and east. They consist of clastic sediments in the main, mostly sandstone and conglomerates;

some horizons are more or less clayey, others are quite calcareous. The alternation of hard and soft horizons of rock is a factor in the irregular topography that characterizes the Allegheny plateau through part of Ohio.

Relief and glaciation. But the irregular relief of this area is the result of long continued weathering. The agents of erosion have acted intermittently. Several drainage cycles have been concerned; one at least is thought to have worked itself to completion, or to base-level; the rest were checked at different stages. The result is the complex physiography, manifest particularly in irregular drainage, which is due chiefly to stream divergence and capture, a subject discussed more fully in a later section (pp. 389–392).

The superficial deposits covering more than one-half of the state are of glacial origin. This glacial drift is a mantle of weathered rock in varying degrees of comminution. Its origin and the complex processes involved in its transportation are more fully considered in the chapter devoted to glaciation. No phase of the geologic history of Ohio is more important than glaciation, which is the basis of the rich soil that has given the state its rank in agriculture.

GEOLOGIC TIME PERIODS REPRESENTED IN OHIO

The rocks of this state dip gently to the south and east. As a result of this attitude, and of weathering since the sediments were deposited, the older formations outcrop in the northern and western parts of the state, and the youngest in the southeastern section. The rocks of the several periods, therefore, have a surface arrangement somewhat resembling that of shingles on a roof, the ridge board being the axis of the Cincinnati arch.

Formations extending from the Ordovician to the Pleistocene periods outcrop in Ohio. Only by aid of the State Geological Map can the boundaries of these periods be satisfactorily followed, in the description below. This map may be procured of the State Geologist, J. A. Bownocker, Columbus, for twenty-five cents; every teacher in the state should have one at hand.

Ordovician. The rocks of this period are on the surface in the southwest corner of the state. They outcrop along the Ohio river east to the valley of Brush creek, Adams county, and northward along the Great Miami river nearly to Piqua, from which place the boundary follows an irregular line southward through Xenia, near Wilmington, and thence to the Ohio river. Westward from the Great Miami, the boundary is very irregular, an arm of the Ordovician rocks being exposed northward along each of the more important tributaries of this river, among them the Stillwater and Twin creeks. Within the area thus described are a few patches of rocks belonging to the next later period; these are outliers or erosion remnants; in the southeast part of the region, also, stream cutting, chiefly that of Brush creek, has given the Ordovician rocks an irregular surface distribution.

Silurian. The boundary of the area just described is the lower contact line of the Silurian formations. From this line the Silurian rocks extend to the east and north as far as Lake Erie, and into Michigan. The eastern boundary of the Silurian is quite regular from Sandusky bay south to Ross county; from Ross county to the Ohio river the margin of the outcrop is irregular, a condition due to river work. Omitting the Ordivician area and a region in the northwest part of the state, embraced by Williams, Fulton, Defiance, Henry, and slight portions of adjacent counties, all of the state west of this north-south line belongs to the Silurian. The Bass islands, and all save the eastern end of the peninsula formed by Sandusky bay, are comprised within Silurian territory. In Logan county, east of Bellefontaine, is an area of rock belonging to the next later period; rocks of the same period are on the surface also in Taylor township of Harden county. With these two exceptions, the territory described belongs entirely to the Silurian. For a distance of about ten miles along the Ohio river west of Vanceburg, Kentucky, the Silurian formations outcrop.

Devonian. The chief exposures of the Devonian rocks in Ohio border Lake Erie westward to Sandusky, and occupy a strip about thirty miles wide extending south across the state as far as Chillicothe. From this point to the Ohio river, the boundary of the Devonian outcrop becomes very irregular and decreases in width; it shows along the Ohio river for about twenty miles east of Vanceburg. Along the Scioto valley, southward from Waverly almost to Lucasville, the Devonian is on the surface; the same outcrop continues westward in a narrow band through Pike county. From the western side of Pike county southward through Adams and Scioto counties the rocks of this period have a very irregular surface distribution. Kelley's island and the eastern end of Marblehead peninsula consist of Devonian formations, as does also the northwest corner of the state, omitting Williams county and a portion of the western end of Fulton county. From Sandusky eastward, the Devonian occupies a narrow strip bordering the lake, narrow as far as the meridian of Unionville, Lake county; east of this meridian, the Devonian outcrop broadens southward into Trumbull county.

Mississippian. In the northwest corner of the state, the Devonian formations border an area comprising all of Williams county and part of Fulton; the rocks of this area are mapped as probably of Mississippian age. The principal area of the Mississippian outcrops extends northward from the Ohio river; this area on the west has a fairly uniform boundary with the Devonian on the west; but on the east, its contact with the later formations is very irregular, the irregularity increasing to the south. The channel of the Ohio river shows Mississippian formations from the Devonian outcrop in southwestern Scioto county eastward to the vicinity of Ironton. Along the east and south-flowing streams, including the Hocking, Licking, Mohican, Killbuck and Cuyahoga rivers, outcrops of the Mississippian reach into the territory of the next later period. East of the Cuyahoga valley the Missippian formations meet the Devonian in a very regular line of contact, but occupy a relatively narrow surface area as far as the meridian of Unionville; beyond this meridian in Trumbull county, the Mississippian area broadens almost to the north-south width of the county. The valley of the Mahoning cuts into the Mississippian rocks as far east as Youngstown. From Youngstown northward, the contact with the rocks of the next later period is quite irregular.

Pennsylvanian. Nearly all the remainder of the state is occupied by the outcrops of this period; in this area is found the most broken topography of Ohio, and the greatest variation in altitude. The Pennsylvanian rocks approach Lake Erie nearest in Geauga county. The boundaries of the different formations of the Pennsylvanian rocks are extremely irregular. In no portion of the state are the streams more numerous. This active river erosion has produced the irregular distribution of the Pennsylvanian formation.

Permian. The exact distribution of Permian formation has not been worked out in Ohio. Their existence north of the Ohio river has been established, and the State Geological Survey is now engaged in mapping the Permian rocks. For this reason the state map makes no mention of this period.

IN GENERAL ON GEOLOGIC PROCESSES

The tearing down of old rocks and building their products up again into new ones, as above described, is a relatively simple process. But simplicity of action is not general in earth-history. Conditions appear constant only because of our limited period of observation. Perhaps in no other science is there less comprehensiveness than in Geology, not only because much of its data does not admit of close study, but also because this data, to be correctly interpreted, must be observed through periods involving the lives of many generations. It is for this reason, that we have so few geologic activities standardized. The mountains are not stable, nor are the seas confined; the former wear away, the latter deepen and shallow. When there is stability in the one and mobility in the other, the line of contact on which both are measured shifts accordingly. So it may be impossible to say whether a certain change in altitude represents an upward or a downward movement of the land, or an extension or withdrawal of the seas. Either movement on the part of either body introduces the appearance of the opposite movement on the part of the other. If the sea withdraws, the area of the land increases; if the land subsides, the sea appears to be extending. But these shifts which vary altitude are only one manifestation of the inconstancy of our land and water bodies. Instead of being able to interpret these movements as due either to a definite uplift or depression of land, or to the extension or retreat of waters, closer study usually shows that there has been a differential movement, indicated here by a certain rate of uplift or retreat, and there by a different rate. While the full value of these movements in time past may never be accurately estimated, it is, however, a satisfaction to know that the students of later generations will have accumulated data on which more satisfactory conclusions may then be based.

The great difference between geology and other sciences is that it imposes upon us greater patience. Our generation can record observations; another, we know not how far ahead, must make the deductions. Formerly some of the earth's functions were catalogued with the supernatural; now many mythological deities and lesser personages have been resolved into simple and usually harmless natural phenomena. In geology the field of fact has spread quite completely over that of fancy. The catastrophies of the past have become the mild, ever active, forces of the present. Mountain-making, canyon-cutting, lava-extrusion, and earth-tremors, are normal functions of the globe. If rivers flow across mountain ranges, it is because the mountains grew so slowly that the rivers held their courses. If a river has cut down into the rocks much more rapidly than it has cut laterally, it is because the region has been subject to relative uplift, thus keeping the river young.

THE RELIEF FEATURES OF OHIO

FRANK CARNEY

Introduction 381
  Composition, structure, and attitude of rocks in relation to relief
  Other influences in relief
  Physiographic regions of Ohio
  River history
Remote drainage of Ohio 387
  Early consequent streams
  Adjustments among consequent streams
  Known for merriver courses
  Development of the Ohio river
Lake Erie drainage 392
Ohio river drainage 396
Summary 400
  Lake plain area
  Plateau area
  Altitudes

INTRODUCTION

The smaller islands of the Pacific are usually divided into two classes: high islands and low islands; these are very simple examples of the relationship between geologic structure and surface features. The low islands consist of organic rock, the products of coral making animals, whereas the high islands consist of volcanic products. In an area like Ohio, involving over forty thousand square miles, we find no such simple conditions as exist in these Pacific islands. A pleasing variety of relief characterizes this state: in the northwest are gently sloping plains, and in the southeast a dissected low plateau; the intervening topography blends easily from one into the other.

Composition, structure, and attitude of rocks in relation to relief. Geologic processes and results are basal to relief. Rock character is generally an important element in a landscape. What the rocks of an area are, and what has happened to them since they were deposited, are the first questions to ask in accounting for surface features.

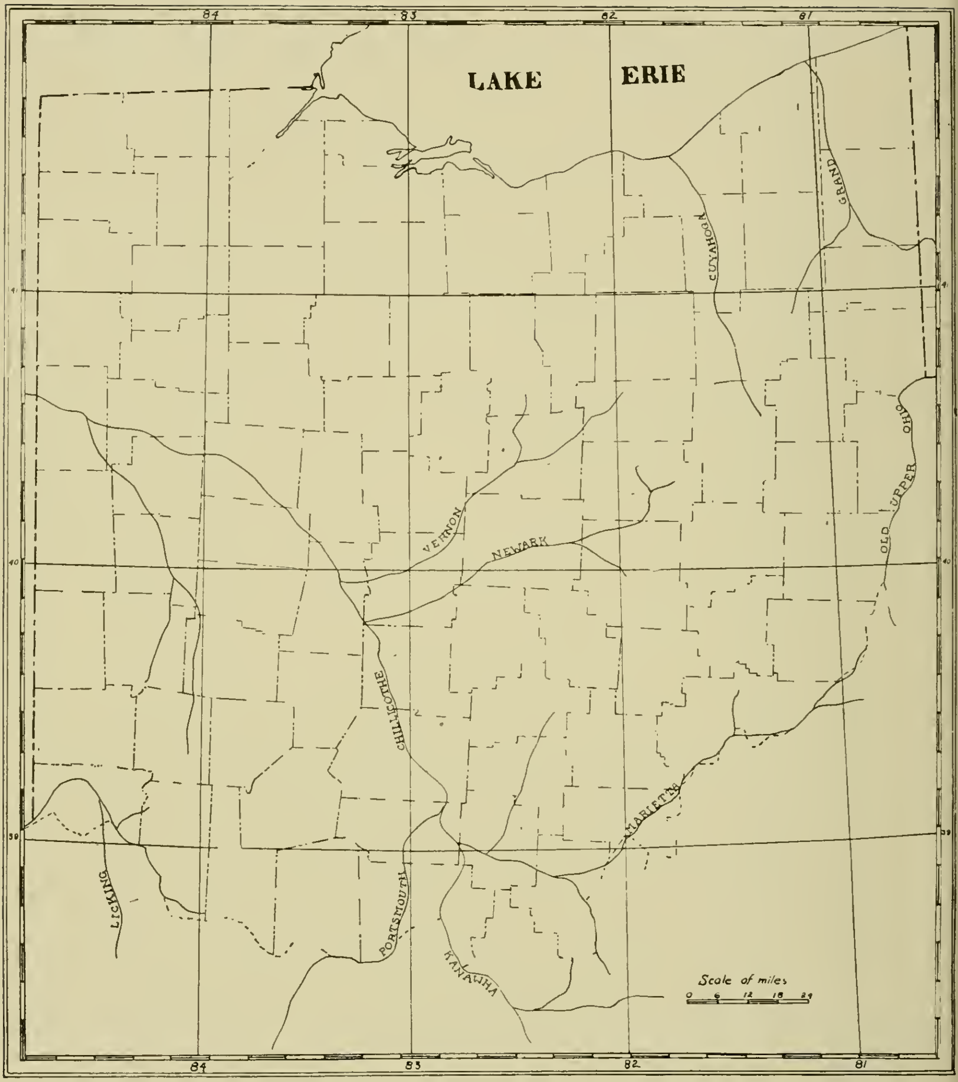
LAKE ERIE
84
83
82
81
41
40
39
CUYAHOGA
GRAND
OLD UPPER OHIO
VERNON
NEWARK
CHILLICOTHE
MARIETTA
PORTSMOUTH
LICKING
KANAWHA
Scale of miles
0 6 12 18 24

Fig. 1. This map, showing a former drainage pattern of Ohio, is based on the work of Tight, Bownocker, Leverett, Fowke, and others. Since the map combines the findings of several investigators, it may not accord fully with the views of any particular one.

Limestones are soluble, hence are readily affected by surface weathering and ground water. Clastic rocks containing a soluble cement yield rapidly to the same agencies. Formations made up largely of either of these types of rock go to pieces much more quickly than do rocks that contain no soluble constituents.

Sometimes the rock has a simple structure; at other times, complex; the simplest structure is an approximation to the horizontal position, the original attitude of most sedimentary formations; the more complex attitudes are found in mountain areas like the Appalachians and the Swiss Alps; jointing and faulting may introduce further complexity of attitude. When the rocks have been highly folded, some of the formations being harder than others, the structural valleys, and the inequalities resulting from differential weathering, give the country a very irregular surface, as illustrated in parts of Pennsylvania.

Massive beds of rock are more resistant than thin layers. Occasionally, sedimentary beds may be heavy, but massiveness is usually associated with igneous rocks.

Furthermore, if the rocks are loose in texture and are fairly homogeneous throughout the district, the stage of strong relief will not endure long; even when such formations have been folded and faulted, but not to the extent of disclosing rocks which differ much in texture and structure, the result will be the same. When thick hard horizons alternate with less resistant strata, irregular topography prevails much longer; the more resistant a given formation is, the longer it withstands weathering, and stamps itself on the topography; even in the absence of crustal deformation, this arrangement of rocks will give some relief, but when the strata have been folded, the surface irregularity is correspondingly greater. Since in Ohio, omitting an area in the southwestern part of the state, all of our formations have a general dip to the south and east, the relief quite accurately reflects the rock texture and structure.

If one starts from Toledo and crosses the state directly to Parkersburg, W. Va., he passes over the outcropping edges of most of the rock formations in Ohio. The first part of his journey is over limestone horizons; this is followed by a belt in which shale outcrops; thus far, the route covers a region of slight relief, largely because the limestone and shale have weathered uniformly. Next he enters a belt of clastic sediments, consisting chiefly of sandy shale and sandstone; the more resistant beds produce slightly greater surface irregularity. For some distance after the traveler has passed the center of the state, he finds himself in more hilly country, where coarse sandstone and conglomerate horizons are on the surface. Following this he enters the coal region, where the sandstone and conglomerate beds are heavier and have better withstood the effects of erosion, giving rise to the most irregular topography in the state. Towards the Ohio river, the streams become more numerous, and the relief more mature.

Had this traveler turned southward from Toledo, soon he would have found himself near the axis of the Cincinnati arch where the formations dip in either direction, on his way to Cincinnati; for some distance the relief is mild, and large streams are wanting, but approaching the Ohio river, the limestone has been cut by streams, and greater surface irregularity exists.

Other influences in relief. Thus the rocks have a marked influence on the elements of a landscape. There are, however, some minor factors that tend to vary the relief which rocks would otherwise always produce. Among these agents are glaciation, and variation in stream history. The deposition of glacial drift generally tends to make the surface features more regular; but in some localities ice erosion has very appreciably increased the relief. Crustal movements, orgogenic and epeirogenic, have induced stream capture and divergence, which frequently account for relief features that do not entirely reflect rock structure and attitude. In another place I discuss these factors more fully (pp. 199–202; 388–392).

Physiographic regions of Ohio. Ohio cannot be parceled into distinct physiographic regions. Its surface has pronounced relief features, but these so blend into each other that it would be rather arbitrary to draw lines of division.

Along the Atlantic seaboard the coastal plain is distinctly set off from the Piedmont belt by the Fall Line. This is a clear cut physiographic boundary. Except for a short distance in the vicinity of Cleveland, and east of that city, we have nothing that even simulates this kind of a boundary. The following is a suggested division for the physiographic regions of this state: (1) the lake plain; (2) the plateau area. These divisions are structural in origin. The first reflects to some extent the minor factors in producing relief features, alluded to above. The second division is dependent quite entirely on underground structure.

It would be erroneous to infer that rock structure and attitude alone account for marked relief. To appreciate this fact, we have only to recall certain arid parts of the world, desert plains, where weathering is due mostly to temperature changes; there the landscape is monotonous, almost devoid of relief; the slight irregularities present usually represent wind deposits.

River and valley development give pleasing details to relief features; the beautiful landscapes have been thus produced. Our range of vision from any particular point seldom grasps more than the irregularities of stream erosion. So, while the basal control in physiography is the rock structure, the details that are within our visual grasp depend largely upon stream work.

River history. There are a few terms that we should understand in any discussion of stream work. All apprehend the fact that if the agents of weathering are given time enough in a land area that continues stable, that is, is neither uplifted nor depressed, these agents will bring the area down to the level of the sea; the agents of disintegration will have crumbled the rocks, and streams will have distributed the products. When, in a given region, the streams have accomplished this, that region is said to have been *base-leveled.* A requisite condition, then, for base-leveling, is a static position of the land area. Whenever earth movements tend to uplift or to depress a region, the stream history becomes complicated and the normal process of base-leveling is either checked or accentuated. A particular river in a base-leveled country may be said to have completed a *cycle.*

The river started at the ocean border as a notch in the rim of the land; its course gradually lengthened; tributaries developed on either side whose courses also lengthened, and widening of the basin continued until no more area could be reached. A stream system, with the aid of the weathering agents at work between its several tributaries, in time reduces its basin approximately to sea level. At first it was a *youthfut* stream, having a steep gradient and a narrow valley; next it passed through the period of *maturity*; and the last stage of its history was that of *old age.* In river development these three stages constitute a cycle; but you observe at once that for the regular development of the cycle, it is absolutely necessary that a static relationship exist between the land area and sea level. This is a theoretical consideration, the ideal way of studying the origin of relief features, and it represents a laudable desire to standardize physiographic processes.

Nature, however, is not always so systematic. Oscillation appears to be the habit of boundary lines between the oceans and the lands. It is not known that any land area ever has remained static long enough for the theoretical development of a river cycle. Instead of being able to point out a particular area where the rivers have had this theoretical life history, we can with more success find the three stages existing contemporaneously in one and the same drainage basin. While the headwater parts of a river system may be in youth, the portion near its mouth will bear the earmarks of old age, and maturity will characterize the parts between these limits.

If the diastrophic movements of our continents were spaced by drainage cycle periods, the land surfaces would then have such roughening as would follow from one plain of erosion giving place to the details of another plain of erosion. In that case, the uplands would be peneplained; and beneath this level the new drainage cycle would cut its valleys. What appears to happen more often is that after a cycle has been under way, its development is either retarded or hastened, and drainage irregularities are introduced. These irregularities may result from the advantage taken of weaker stream basins by the more vigorous drainage basins. Thus, when a land-tilt appreciably increases the velocity of one river, it correspondingly retards the current of the river flowing in an opposite direction from the same divide, and, as a result, the former encroaches on the drainage territory of the latter. This is river *piracy*.

While piracy generally follows from land-tilts, as just mentioned, it may also occur when one of two streams, which are balanced, cuts into harder rock, while the other stream continues in the original homogeneous strata. The latter deepens its channel and widens its valley, as both did formerly; but the other stream, having to work against more resistant rock, is not able to cut its channel correspondingly, and as a result loses drainage area to the former. Such piracy is not based upon land-tilting, but on rock structure. Furthermore, both land-tilting and variation in the hardness of the rocks are usually operative at the same time.

In some parts of the world normal drainage cycles have been suddenly interrupted by lava flows. A flow of lava, taking a course across a valley, in a very short time forms a dam that may divert the drainage. This has never happened in Ohio. There are still other minor and infrequent natural operations that tend to produce irregular drainage history.

It is impossible to reconstruct the drainage history of Ohio from the time its area was first raised from the sea. Remote phases are quite beyond interpretation, and there is not complete agreement among students as to the details of more recent phases.

Under the leadership of Prof. W. M. Davis,[1] much progress has been made in the analysis of relief features, and in the knowledge of the processes involved. He has given the literature many terms that aid in the discussion of drainage evolution. When a tract in the shallow part of the sea margin is added to the continent, the first streams that form across it are called *consequent,* that is, the water finds inequalities in the surface, along which the flow is established to the sea. The streams of Florida belong to this class.

REMOTE DRAINAGE OF OHIO

Early consequent streams. When, late in the Permian period, the last portion of the Ohio area rose permanently above sea level, consequent drainage was established in the southeastern part of the state. The direction of these streams, and of the rivers already existing in other parts of Ohio cannot be demonstrated, but it is felt by many geologists that our area previously had been a portion of a great Mediterranean sea which for a long geologic time had occupied the region of the Mississippi basin; and that this sea only on rare occasions was connected with the Atlantic ocean across the central and northern Appalachian region. If this hypothesis is correct, it is probable that the original consequent streams had a southern course, to the diminishing inland sea, and later were tributary to a major stream which flowed southwest through eastern Kentucky and Tennessee. Possibly in the northwest part of the state, along the west flank of the Cincinnati arch, the original consequent streams flowed westward.

The Atlantic coastal plain drainage and the theoretical consequent drainage of part of Ohio in post-Permian times are not unlike in principle. The rock material of the Atlantic coastal plain area was deposited by the streams flowing to the east and southeast, streams which carried sediment into the bordering ocean, whose currents distributed it; when this epi-continental tract was added to the land, the consequent streams also took a south and southeast direction, to which they still hold. The sediment that formed the rocks of much of Ohio was spread by streams, coming probably from a northern source, into a sea that grew deeper to the east and south; therefore, the natural dip of the rocks resulting from these deposits is towards the south and east.

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[1] *Geographical Essays,* Boston, 1909.

Adjustments among consequent streams. Not long, geologically, after the region of Ohio was uplifted finally from the sea, or the sea withdrawn from it, the whole area, because of the mountain-making disturbance to the east, was warped. In the east this disturbance continued till the formerly horizontal rock beds were folded into the parallel ridges of the Appalachian mountains; in Ohio the disturbance is represented by the Allegheny plateau. This dynamic movement progressed very slowly; the rivers underwent adjustments, probably leading much of the original consequent drainage westward into the Mississippi basin, via northern Indiana.

The drainage pattern that develops in a shift from the consequent stream courses depends very largely on the relationship of the rock horizons in which the valleys are being cut. When the formations, which are not horizontal, alternate in hardness, and are transverse to the direction of the stream flow, ridges of resistant rock will appear across the area between the rivers, and *subsequent* streams will develop valleys laterally through the intervening belt of softer rocks; thus, the valley of the major consequent river has a gorge-like form alternating with wide mature reaches, because of the contrasts of hardness in the formations. With the lapse of time, and the succession of several incomplete drainage cycles, the ridges will be more and more obliterated. It is probable that the drainage pattern, developed in Ohio after the slow disturbances incident to the folding of the Appalachians, endured for a long time.

One can only offer suggestions as to the various steps between the original consequent rivers and the establishment of present drainage. Many investigators have studied this problem. Some general principles in connection with drainage evolution in Ohio are understood, even though the complete history cannot yet be written. It is known that the relation of our continent to the ocean has shifted several different times since the Permian period. The altitude of the Ohio area has varied with these shifts. Following an upward movement of the land, stream work was accelerated; following a depression, the stream velocity was checked. Under the latter condition, flood plains would appear in the valleys; whereas the former movement would trench and remove material from the flood plains, and lengthen the rivers through piracy. Furthermore, it is generally felt that other periods of fairly static relationship between land and water existed; during such intervals, the streams and valleys tended to develop a complete drainage cycle. One such period, the Cretaceous, is said to have witnessed, in some parts of eastern North America, a base-level cycle. At the close of this period, the land area of North America was much diminished, and the epi-continental part of the ocean was very wide. The succeeding oscillation of the shoreline must have produced many changes in the streams. From this time, the drainage history of Ohio appears to admit of more satisfactory study.

Former river courses. So much of the state bears a deep mantle of glacial deposits that a long time may elapse before the buried river channels will have been located to such an extent as will warrant a satisfactory reconstruction of the old drainage of Ohio. In many counties, even where the land surface is level, well-borings have disclosed an irregular rock surface, sometimes cut up by the gorges of young rivers, sometimes showing the gentle slopes of old-age valleys. In the unglaciated area of the state the former drainage lines are more easily deciphered.

The problem of figuring out the river valleys of the past is further complicated by the fact that much of the glaciated part of the state appears to have been, from early times, a lowland toward which the rivers flowed from the non-glaciated area. Many abandoned valleys, conspicuous outside the drift sheet, have been followed into the drift-buried area, and their further tracing rendered impossible save where well-borings are numerous. For these several reasons, the map (fig. 1), giving a reconstructed drainage of Ohio, is largely hypothetical. Corrections will be made in time, particularly if activity in sinking deep wells should continue. The former river courses here indicated are supposed, in the main, to have antedated the course of the Ohio river along the southern part of the state. Segments of these former stream valleys were united in forming the Ohio.

The central and western parts of the state, omitting the lake plain area, appear to have been drained by two important streams, each having a large basin and many tributaries, which united in or near Mercer county, flowing thence into Indiana. The course of the westernmost of these streams, in parts of Warren and Green counties, is indicated by the Little Miami; it passes thence across the southwest corner of Clarke county, and bears northwestward through Troy and Piqua into Shelby county.

The drainage history in the southwest corner of the state has been variously interpreted by different workers. One reconstruction gives two streams, rising in Kentucky, flowing northward, uniting near Hamilton into one stream which followed the course now indicated by the Great Miami through Dayton, northeast of which, in Clarke county, it joined the buried channel just described; the Licking river is one of the streams; its old course and present course are identical north to the Ohio, and Mill creek valley is its abandoned course northward from Cincinnati; the other stream flowed northward to Hamilton through the Great Miami valley. Another reconstruction assumes that the old Licking river turned to the southwest at Hamilton and made the valley which the Great Miami occupies in its course to the Ohio.

The central part of the state is today drained southward by the Scioto. The former river in this area, it is supposed, flowed to the north, its several tributaries rising in Kentucky and West Virginia. One of these branches, the Marietta river, had its headwaters in the vicinity of Parkersburg; for a few miles, the Ohio now follows its valley; thence this stream crossed Meigs county, and the northern part of Mason county, Ky., and continued westward through Gallia and Jackson counties, Ohio, uniting with another stream from the south, the old Kanawha,[2] in the vicinity of Beaver, Pike county. Near Piketon, the Kanawha joined the old Portsmouth river which also had its origin in

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[2] Tight names this, Teays river. *Professional Paper 13*, plate xvii, U. S. Geol. Survey, 1903.

Kentucky and flowed northward through the present Scioto valley; from the vicinity of Manchester, to Portsmouth, the Ohio follows the valley of the former river. For a few miles north of Waverly the Scioto follows the valley of this old stream, in reversed direction; the river formed by the union of the Portsmouth and the Kanawha has been named the Chillicothe, the buried course of which is supposed to run west of north for some distance, then in a more westerly direction, uniting with another buried river in or near Mercer county. From the east, between Chillicothe and Columbus, the Chillicothe received two tributaries. The northern of these has been called Vernon river, as Mt. Vernon is situated in its old valley. The southern stream is named the Newark river, which was formed by the junction of tributaries in Coshocton county, and flowed westward past Dresden, Hanover, and Newark; the Muskingum today leaves this old valley in the vicinity of Dresden and flows southward through Zanesville, entering the Ohio at Marietta. In part of Muskingum county, and continuing into Licking county for a few miles west of Newark, this abandoned valley is a very obvious topographic feature.

The map of the former drainage lines of Ohio shows a river rising probably in Tuscarawas county, and flowing through Akron, north along the valley now occupied by the Cuyahoga river. South of Akron the drift is very level, giving no suggestion of the valley carving which it covers.

The Grand river is but a small portion of an old river which flowed northward; the present stream follows the former valley for a short distance. This old stream, the Pittsburg river, drained much of western Pennsylvania, and had its origin in West Virginia, being identical, south of Pittsburg, with the Monongahela. From the vicinity of Beaver, Pa., two branches have been traced southward; the easternmost passed the present site of Pittsburg; the course of the western branch is followed by the valley of the present Ohio to the vicinity of Wheeling and possibly as far south as Monroe county. Parts of the Allegheny were also included in the Pittsburg river basin, which is drained today by portions of the following rivers: Grand, Mahoning, Allegheny, Monongahela, and Ohio.

The above-mentioned rivers carved the main valleys in the former river basins of Ohio. These had numerous tributaries, many of which have been worked out; some of them form parts of the present drainage lines. Several rivers which enter Lake Erie flow across buried valleys; at the place of intersection, the modern stream has a much wider valley than on either side of the former river course.

The development of the Ohio river. From the preceding discussion it appears that the Ohio, throughout the part of its course which borders our state, is a composite stream. Between these ancestral streams, important divides existed at the following points: (1) near New Martinsville, (2) in the vicinity of Huntington, W. Va., (3) east of Manchester, (4) between Cincinnati and the Great Miami. The Ohio river was brought into existence, then, by stream capture or piracy cutting down these divides. The order in which the captures took place cannot be stated, nor has it been demonstrated what was the agency that induced the captures. That the Ohio had practically its present course before the first ice invasion affected the state, is probable. It appears, therefore, that the direction of river-flow in the part of the old Pittsburg valley which bore a north-flowing stream from the vicinity of New Martinsville to Beaver, Pa., has been reversed. Reversals of flow have also taken place in some other segments of this composite river.

More satisfactory work has been done in unraveling the origin of the Ohio river than in other studies of former drainage in the state, for the reason that glaciation has only slightly affected this stream. All the rivers from the north, during most of the time that the ice was in the state, were heavily loaded with outwash, which silted up the valleys, even that of the Ohio to some extent.

Lake Erie Drainage

No large rivers, belonging entirely to this state, empty into Lake Erie; the Maumee, which is of considerable length, rises in Indiana. In the eastern half of the state the rivers are short, because the present divide between the Ohio and the Erie basins is nearer the latter. In the western half the rivers are longer but somewhat complicated, because of glacial deposits. I will briefly describe these rivers, commencing on the east.

Conneaut creek. This stream has its sources in Pennsylvania. Its course for several miles is quite parallel to the lake shore, a direction of flow caused by the east-west trend of a moraine which the stream crosses a short distance east of Kingsville in Ashtabula county. After crossing the moraine, the creek turns eastward along the beach of glacial lake Whittlesey for about two miles; then it cuts through the beach, but after flowing north one mile its course is diverted to the east again by the abandoned shore ridges of lake Warren. At Conneaut the creek channels the Warren beach, and flows directly north to the lake.

Conneaut creek is a typical example of the influence which moraines and the beaches of ice-front lakes have exercised on the direction of post-glacial streams.

Ashtabula river. This stream also rises in Pennsylvania; it flows thence across the northeastern part of Ashtabula county. In some places the Ashtabula has cut a beautiful channel through the lower Pennsylvanian sandstones. Its course is very irregular where it crosses the moraine referred to above. The city of Ashtabula has grown along this river northward from its intersection with the Whittlesey shoreline; nearly the entire distance of three miles between this beach and Lake Erie, the river is bordered by this rapidly growing city, a response to the harbor facilities and the steel industry.

Grand river. This stream rises in Trumbull county and flows almost directly north to within about twenty miles of the lake, when it is diverted to the west by a heavy band of moraine. A few miles south of Painesville it bears northward again, entering the lake through a narrow gorge cut in Cleveland shales. Throughout the last mile of its course, however, its banks are not high. That the Grand river has been much shortened, perhaps in part through glacial interference, has already been stated (p. 391). In some parts of its course, a canyon-like cross-section shows how the declining level of Lake Erie, lower now by about 170 feet than the level to which the river was once graded, has tended to beautify all the streams now tributary to it.

Chagrin river. The major part of its basin lies in Geauga county, though its remotest tributary rises in Portage county. This stream also has precipitous cliffs through much of its course. The Cleveland shales have been easily eroded as the stream has lowered its bed to its present base-level. The multiplicity of tributaries from Geauga county represents the influence of the harder Pennsylvanian rocks.

Cuyahoga river. This river has a remarkable course. Its remotest source is not far from Lake Erie. Thence it flows south and west; near Cuyahoga Falls it turns to the north, entering the lake at Cleveland. One at once recognizes something irregular in this drainage pattern. Possibly glaciation has had much to do with its course; from Cuyahoga falls northward the river occupies a very mature valley. This maturity is such as would lead one to infer a genesis in connection with a much longer stream. At some time in the past a river which had its origin far south flowed northward, along the route taken by the canal to Akron (p. 391); and the present Cuyahoga occupies only the northern end of this former course. The south-flowing section of the Cuyahoga, starting in Geauga county, drains at first a hilly region, but from the vicinity of Kent its course lies in a level country. This flat plain contains many small lakes and swamps, and is obviously of glacial outwash and morainic origin. The falls occur where this northern section of the Cuyahoga turns into the valley of the former stream. Between Cuyahoga Falls and Cleveland some local irregularities in the river have been introduced through glacial interference.

Rocky river. The headwaters of this short stream are found in Medina county, whence it flows in two main branches that unite north of Berea. These tributaries have their origin in the more irregular topography of the Pennsylvanian rocks. At Berea and Olmsted Falls both branches have a waterfall, due to the Berea sandstone. Between these falls and the lake, the Rocky river occupies a gorge cut in the Cleveland and Erie shales. Northward from the point where the branches come together, the present channel flows twice across the channel occupied by a preglacial ancestral stream, which is called the Preglacial Rocky river. There is no more obvious case of drainage change in the state than this river.

Black river. This stream rises in Ashland county, flowing thence to Medina; west of Lodi it turns to the north and crosses Lorain county. The change of direction in Medina county appears to be due to an east-west moraine, to which the river is parallel. South of Grafton the river commences to flow on the Berea sandstone. Owing to the gentle dip of the Berea, it continues in this formation to Elyria. From Elyria northward to within about a mile of the lake the stream follows a rock channel cut in the Erie and Ohio shales. Some of the smaller tributaries of the Black river in Lorain county exhibit the directive influence of the lake ridges.

Vermilion river. This is also a short stream. It rises in Ashland county, and because of a difference in rock structure has a flatter cross-section in the Huron county part of its course than has the Rocky river; but in the northern part of Huron county it cuts through the outcropping Berea sandstone into the underlying shales; this part of its course is a rock channel, in some places very beautiful. In the last two miles of its course the river is sluggish.

Huron river. The sources of this stream are in Seneca and Huron counties. It has a general northward course, passing Monroeville and entering the lake at Huron. South of the central part of Huron county its channel is cut in the Berea sandstone, locally forming beautiful scenery. Nearing Monroevill the underlying shale outcrops, and the stream has cut deeply into this easily eroded horizon; at Milan the channel shows fifty feet of shale bank. These cliffs gradually die out, and through the last four miles of its course the river has a wide valley and is very sluggish. Along the Huron, in the vicinity of Monroeville, the shales contain numerous large concretions; many have fallen from the banks and are so large that the stream does not at once carry them away.

Sandusky river. Of the rivers so far discussed, this has the largest drainage basin. Its numerous headwater streams start in Richmond, Marion and Hardin counties. Some of the tributaries flow to the southwest before joining the major branches. This direction of flow reflects the influence of moraine ridges on drainage; the glacial map of the state shows how the moraines in this part trend south of west. The Sandusky cuts into limestone throughout nearly all of its course; only at a few places does shale appear in the channel; the last few miles of its course, before emptying into the Sandusky bay, are in the area of the Monroe formation.

Portage river. This short river rises in Hancock county. Its basin includes nearly half of Wood county, a small portion of Sandusky county and some of Ottawa. The Portage has not cut a channel of much importance anywhere in its course; the rocks disclosed by it are limestone.

Maumee river. This is the major stream of many smaller rivers that belong to the northwestern part of Ohio. The Maumee itself rises in Indiana. Of its Ohio tributaries the principal are: on the north, the Tiffin river, which flows southward from Michigan, joining the Maumee at Defiance; on the south, the major tributary is the Auglaize, which rises in an extensive swamp section northwest of Kenton in Hardin county. One of the more significant tributaries of the Auglaize is Ottawa creek which rises near Ada, also in the swamp district. The Blanchard river, another branch of the Auglaize, flows from the same marsh area in Hardin county; for about twenty miles, its course is directly north; reaching the meridian of Findlay, it turns westward through Ottowa, and joins the Auglaize near Dupont. Many other smaller tributaries, on account of the direction of the moraines, also have a general westerly course. On its western side, the Auglaize has numerous small branches draining Paulding and Van Wert counties. The river takes its name from the fact that several of its headwater streams rise in Auglaize county.

From Defiance to Toledo, the Maumee is a very sluggish stream. It has not been of much use in navigation, as appears from the fact that a canal had to be built along its channel. Wood, Henry and Fulton counties give rise to several minor tributaries of the Maumee.

OHIO RIVER DRAINAGE

The longest rivers of the state are tributary to the Ohio. Many of these, when studied closely, show puzzling relationships. The Ohio itself has had an intricate history; some of its tributaries embody even greater complexities of origin, as already described.

Great Miami. The general course of this stream, whose basin involves about 4000 square miles, coincides with the axis of the Cincinnati arch. At first thought it may appear as an anomalous condition for a river to flow along the axis of an anticline. When such an anticline involves limestone formations, ultimately the drainage takes just such a course. The principles involved in the development of such a course have been fully discussed and illustrated in drainage studies in the Appalachian areas, by Professor Davis.[3]

The remote sources of the Great Miami are in Hardin county. Since so many rivers rise in this county, it would appear that the region must have a relatively high altitude; the cause, however, is rather the glacial deposits which have converted much of the area into a great swamp. This swamp, in effect, is a broad divide. Numerous streams usually flow away from an extensive marsh area. From Dayton northward, the Great Miami has many branches. At Dayton it receives the Stillwater creek, and Mad river. Each of these tributaries is quite complex; the former drains nearly all of Darke county; the latter, Springfield and Champaign counties and parts of Logan. The remainder of Logan county gives its drainage to the Miami proper. Much of the surface water of Shelby county is gathered into Loramie reservoir, which overflows into the Miami. From Dayton southward, this river follows a mature valley, and only its tributaries at some distance from the flood plain show any evidence of youth. The Miami has no very long branches between Dayton and the Ohio river; on the west are several small creeks, some of them rising in Indiana. The junction of the Great Miami and the Ohio is formed just across the state line in Indiana.

Little Miami. This stream, about 100 miles long, has its source in Clarke county. Its basin, involving about 1850 square miles, includes parts of Greene, Clinton, Highland, Brown, Warren, Clermont and Hamilton counties. This river is parallel to the Great Miami; and its nearness to the larger stream accounts for its receiving from the west no branches of any consequence; on the east it has tributaries that rise many miles away.

Scioto river. The drainage basin of this stream is asymmetric: it receives few and short tributaries from the east, while the western side of its basin gives many long branches. The remotest headwater sources of the Scioto rise in Morrow, Crawford and Auglaize counties; its length is 210 miles, and it drains an area of 6400 square miles. An interesting feature of this stream is the numerous quite parallel branches that cross Delaware and Franklin counties. Of these the Big Walnut, Allen creek, and Olentangy are found within an east-west distance of ten miles; they are slightly farther apart on the northern side of Delaware county. The Olentangy unites with the major stream at Columbus, while the Allen and Big Walnut creeks come together near Groveport, and a short distance south, join the Scioto. This arrangement of parallel streams may represent an inheritance from the excessive drainage of the immediate ice-front. The Scioto occupies a wide preglacial basin; and as the ice sheet assumed new retreatal positions, the drainage from quite a distance along its front centered toward the axis of this basin. Whenever the ice maintained a fairly stationary position, building up a conspicuous moraine, as it did in the vicinity of Worthington north of Columbus, great volumes of water flowed southward from the moraine.

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[3] *Loc. cit.*, pp. 434–441.

South of Columbus on the west, the Scioto receives Darby creek from Logan county and Paint creek from Madison county. There are several other smaller streams that drain the western side of the Scioto's basin. From the east the Scioto receives but two branches of much length: Walnut creek rises in Fairfield county, and Salt creek has tributaries reaching into Hocking, Vinton and Jackson counties.

The lower course of the Scioto is rock bound, the channel being cut in the Waverly sandstone. Its fall even from Columbus to the Ohio is not great, about 200 feet in 90 miles. The Ohio canal follows the Scioto to Lockbourne.

The barbed pattern formed by the Scioto and its tributaries is the best example of normal river arrangement in Ohio. When a tributary joins its major, the smaller angle made should be on the upstream side; this forms the barbed pattern. If you examine the relationship between major and tributary streams throughout Ohio, you will note how nearly the Scioto basin conforms to the barbed arrangement.

Between the mouth of the Scioto and the mouth of the Hocking river, the Ohio receives very few tributaries, and all of these are small. The first one upstream is called the Little Scioto; its drainage basin extends across Scioto county, and includes the southwestern part of Jackson county. Another of these streams, Symmes creek, has its source in Jackson county, and flows southward through Gallia and Lawrence counties; it crosses an irregular country, a region of Pennsylvanian sandstones and conglomerates. The Raccoon creek, the largest of these tributaries, rises in Hocking county, and flows directly south through Clinton and Gallia counties to the Ohio; some of its branches drain portions of Athens and Meigs counties. The Raccoon is an irregular stream, its valley having wide and narrow stretches alternately; such a relationship suggests a composite history. Meigs county is drained entirely by minor creeks tributary to the Ohio.

Hocking river. This stream has a length of about 100 miles and a drainage basin of approximately 1200 square miles. Its remotest source is in Fairfield county, and its numerous tributaries form a basin including parts of Perry, Morgan, Hocking, Washington and Athens counties; this basin involves rocks of the Pennsylvanian period, consequently it drains a rugged region. Its bed has a fall of about 240 feet, but not a uniform slope; in some segments of the valley the stream has very little flow, while in other segments it is cutting into rock.

Muskingum river. This has the largest basin and is the longest stream in Ohio. Its length is about 200 miles, and the area drained has been estimated as 7,740 square miles. The maximum width of this basin is 100 miles. One of its major tributaries rises in Medina county, within about 40 miles of Lake Erie. The Muskingum proper is formed by the junction of two streams, the Walhondling and the Tuscarawas. These meet in Coshocton county; the name, Muskingum, is applied to the river south from this point of junction. Each of these uniting streams has an irregular course and numerous tributaries. The Walhondling drains parts of Knox, Morrow, Richland, Ashland, Medina, Wayne, Holmes, and Coshocton counties; the basin of the Tuscarawas embraces all or parts of the following counties: Harrison, Belmont, Carroll, Columbiana, Stark, Summit, Medina, Wayne, Holmes and Tuscarawas. It is thought that glaciation has been an important factor in producing the irregularity of both these streams. The country drained is rough, since throughout most of it the coarse Mississippian and Pennsylvanian rocks are on the surface.

Will's creek, the basin of which includes all of Guernsey, and parts of Belmont, Noble, Monroe and Coshocton counties, joins the Muskingum about 10 miles south of the junction of the Walhondling and the Tuscarawas. The next important tributary of the Muskingum is the Licking, with which it unites at Zanesville. The basin of the Licking embraces practically all of Licking county and portions of Knox, Perry, and Fairfield counties. The Licking is a composite stream, the result of drainage modifications antedating the last glacial epoch. Between Zanesville and Marietta the Muskingum receives no important tributaries, no creek more than 20 miles long.

So far as investigation has proceeded, the Muskingum also surpasses other streams of our state in its interesting history. Students were early attracted by the drainage irregularities so obvious throughout its basin. Many of these have been unraveled, so that now it is possible to trace the history of this river to an early date.

Following the Ohio upstream, from Marietta to the Pennsylvania state line, we find no important tributaries, and only two that measure more than 20 miles in length. Entering the river less than two miles east of Marietta, is Duck creek, which drains most of Noble county and receives some accessions on its way to the river through Washington county. About two miles farther upstream, we find the Little Muskingum, which rises in Monroe county and takes an irregular course southwestward, parallel to the Ohio river.

The divide between the Ohio river and the Muskingum is so near the Ohio that it receives from the west no important branches between Marietta and East Liverpool. In time these short Ohio tributaries may push their headwaters westward at the expense of the Muskingum drainage basin.

Little Beaver river. Most of Columbiana county is drained by this stream, which has numerous branches. It is a short river but embraces some interesting features. A small part of its course, just before meeting the Ohio, lies east of the state line.

Mahoning river. Portions of Trumbull, Portage and Stark counties and nearly all of Mahoning county are within the basin of this stream, which joins the Beaver river at Newcastle, Pa. Its headwaters reach into some high altitudes where the Pennsylvanian formations outcrop.

SUMMARY

There is much variation in the character of the relief of Ohio; but the areas illustrating the different types are not set off sharply from each other; they blend so well that the observer scarcely notes the change in passing from the youthful topography into the more mature dissection. From the standpoint of the river cycle now in operation, there is no typical old age topography in the state; on some uplands, between troughs that are still being deepened, one may see the broad gentle slopes of old age, the remnants of an older base-level period.

Lake plain area. In the north and northwest parts of the state, the relief is youthful. This is the region of the old lake plain and the adjacent prairie land. The streams, since the retreat of the glacier, have been working to the base-levels formed by the different stages of Lake Erie; there have been three important stages preceding the present (p. 214). Nearly all these rivers have gorges that extend back a few miles from the lake; the size of each gorge varies with the texture of the rock in which it is cut. At a few places along the lake the streams are carving their channels entirely in glacial drift; but the glacial drift, the shale, and the soluble limestones, yield quite readily to erosion.

Another feature of the youthful topography in the lake plain region is the extensive swamp areas; a long time will elapse before the rivers will have pushed their tributaries across these swamps. The state, therefore, is constructing artificial channels which lead to the nearest streams, thus hastening what nature unaided would do in time.

Plateau area. In the plateau area there is much more dissection. Here are the headwater branches of the streams that belong to the Ohio river and to the Lake Erie basins. This condition of more advanced relief is not constant throughout the area. In some parts post-glacial rivers have done but little trenching, and the relief is largely the work of older drainage; the surface is rolling and the minor divides are very irregular.

The Ohio river is the immediate base-level of all these south-flowing streams, but at particular places along their courses horizons of resistant rock form local base-levels, to which the up-stream parts for varying distances become graded. The whole area is quite thoroughly drained; the stage is mature, but less mature than would be anticipated at such a distance from the sources of so long a river as the Ohio. The absence of relief of at least an early old-age stage, in southern Ohio, considering the length of the Ohio river, is due to the origin of this river, as already explained (p. 392). Down the river towards Cincinnati the relief is more immature; the stage of dissection, however, does not change uniformly upstream, a condition which reflects the river's composite origin; the divides between the segments of the streams which were united in forming the Ohio river are characterized by more youthful dissection. Throughout the whole of the plateau area the streams are fairly well adjusted to the rock structure.

Altitudes. Ohio has an altitude range of about 1100 feet. The highest point, 1540 feet, is in Logan county; the lowest, 440 feet, is the low-water mark at Cincinnati. The Ohio river drops about 220 feet in the 436 miles of its course along the state. According to the *Dictionary of Altitudes*[4] the following are the altitudes for the low-water mark at various points upstream from Cincinnati: Maysville, Ky., 448; Portsmouth, 468; Ironton, 483; Marietta, 570; Moundsville, W. Va., 614; Wheeling, W. Va., 622; Steubenville, 641. The Wellsville topographic sheet shows the 660-foot contour crossing the river at East Liverpool.

Lake Erie is 573 feet above sea level; within the lake plain region are included the adjacent areas below 800 feet in altitude. A relief map of the state shows that the plateau area consists of five north-south blocks that are over 1000 feet high; these are separated by lower strips through which flow the important rivers of the state. In the south central part of the state, between the valleys of the Scioto and the Muskingum, the general altitude is less than 1000 feet. The north-south blocks of higher altitude increase in surface irregularity and in irregularity of outline from west to east; the most eastern block does not contain any east-west gaps north of Washington county. The general parallelism of these blocks, their ragged outlines, and the intervening lower strips, have exerted a strong influence in the industrial development of Ohio.

[4] U. S. Geological Survey, 1906.

GEOGRAPHIC CONDITIONS IN THE EARLY HISTORY OF THE OHIO COUNTRY

Frank Carney

- Routes to Ohio 403
    - St. Lawrence river
    - Mohawk pass
    - Mississippi river
    - Appalachian gaps
- Early efforts to reach the Ohio river 406
    - La Salle
    - The Virginian expedition
- Claimants of the area now Ohio 408
    - Claim of the Iroquois Confederacy
    - Claim of the French 409
        - Basis of claim
        - Competition in fur-trade
        - Equity of claim
    - Claim of Great Britain 411
        - Royal charters
        - Discovery by John Cabot
        - Deed from the Iroquois Confederacy
        - The French and Indian War
        - George III's "royal domain," and the Quebec Act
        - Difficulties with Indians in enforcing claim
        - The trans-Appalachian area secured to the English
    - Claim of Virginia 416
        - Population of Virginia
        - Dunmore's Indian War
        - Campaign of George Rodgers Clark
        - Influence of Clark's campaign in Peace of Paris, 1783
    - Claim of the United States Congress 419
        - State claims conceded to the federal government
        - The Northwest Territory
- Summary 420

Routes to Ohio

A colony is much more than a trading post; a colony is a group of people devoting themselves to procuring a living from the soil. No new land is ever permanently occupied until it has been divided into farms. The settlement of Ohio commenced when farm homes were established within its borders, not when fur-trader's posts were located.

Certain physiographic conditions are factors in the exploration and the succeeding settlement of the lands. Man in later centuries may progressively become less subject to the physical features of the earth; but he will never become able to ignore them. Mountains will always be mountains to him; plains, low easy places for his activities; and rivers, the lines of his movement across the lands. This is just as true when he moves no longer on boats, but in freight cars and Pullmans; river valleys attract railroads as well as the overland caravans of pioneers.

Reports of the beauty of the Ohio country, its great river and lake, had come to the ears of white men through the Indians. Sporadically, for several decades, men from the coast colonies had attempted to reach the region, but were thwarted. Without the modern methods of travel, to set out for a terminus several hundred miles away in a wilderness, is a serious matter. Even today the area is reached usually by definite physiographic routes. Four routes were used in the early days.

St. Lawrence river. An explorer, entering North America by the St. Lawrence and keeping away from the southern shore of the lakes, on his way into the interior, would cross the narrow river between Lakes Erie and Huron. By this route, many of the early French travelers reached the northwest territory. Doubtless they might have chosen a route lying south of the lakes, but because of a serious mistake made by an early French explorer, Cartier, the Indians living south of Lake Ontario were bitter enemies of the French; the French, except when prompted by missionary motives, usually kept away from the southern shore of Lake Ontario. Probably the first white man who visited the Ohio area entered this western country by the northern route.

Mohawk pass. Another way of approach is through the lowland of New York State, the Mohawk valley, which is the lowest gap across the Appalachian mountains. This is the route through which today moves the bulk of the industrial output of the Mississippi valley on its way to the Atlantic cities and to Europe. The Mohawk lowland afforded a convenient water-course to the west, Clinton's "ditch," joining Lake Erie and the ocean; and later became the route of those great, effective lines of railroad, the New York Central and the West Shore, the extensions of which through Canada and northern Ohio now form connections that reach to the Pacific. The most natural and therefore easiest approach to Ohio from the Atlantic is across New York State, but it was not the route taken by the first settlers who came into Ohio.

Mississippi river. Ohio may also be entered from the west, through a door as wide as the distance between Lake Erie and the Ohio river. An explorer ascending the Mississippi, following the Ohio to the east, and one of its larger tributaries to the north, would have found an easy portage to the Maumee, thence into northwestern Ohio. Joliet appears to have entered Ohio from the west, but it is not known where he crossed what is now the state line.

Appalachian gaps. The fourth route into Ohio is one which, as far as settlement is concerned, was the first used, the route across the Appalachian mountains, gradually rising many hundred feet above sea level, and then slowly dropping into the low plateau and the plains beyond. The altitude of the Appalachians was formidable; their rugged wilderness condition, extending three hundred miles when crossed by the most direct route and much longer when crossed by other passes, was forbidding. Traders and adventurers occasionally worked their way over the barrier; but colonists did not attempt it till compelled to do so.

Every river that enters the Atlantic was tried for "South Sea" affiliations, during the days of exploration. Each explorer thought: this is the strait that will lead me through the barrier of land between European markets and the wealth of the East. The Potomac was thus explored; it did not lead to the silks and spices of Asia, but later was effectively used both for canal and railroad to transport the far more valuable coal and grain of the Allegheny plateau and Mississippi basin.

The Potomac rises near the Cumberland pass, on the west side of which the pioneer had a choice of route, either northward down the Youghiogheny and Monongahela to Pittsburgh, or more directly westward towards Wheeling. This pass through the Appalachians was much used, used even by emigrants from New England. The route itself did not attract settlers, for the mountains were rough, and the valleys heavily wooded; the emigrants therefore pushed westward into the plains beyond. The

Hudson and Mohawk valleys, on the other hand, tempted emigrants to stop at every point; consequently the New York route itself was found attractive and was settled almost completely by the Dutch, whereas later colonists had to push on farther west.

Emigrants from the southern settlements, after crossing the Blue Ridge mountains, sometimes proceeded southward through the Great Valley to Fort Chiswell; at this point they turned to the west across the Holston and Clinch valleys, and through the Cumberland Gap into the "western" country.

EARLY EFFORTS TO REACH THE OHIO

In recent decades immigration to Ohio has been very active, drawing people mostly from two extremes of social and financial standing. Her numerous and evergrowing industries are attracting laborers from Europe, and capitalists from other states. These two sources are making valuable contributions to her list of citizens.

La Salle. It is doubtful, however, whether any man who has come into Ohio since the French and Indian War sought the area more eagerly than did La Salle in the seventeenth century. La Salle was an intrepid explorer, and gifted with much diplomacy in dealing with the Indians; he sojourned for some time among the Iroquois in central New York. While he and his two Sulpitian companions were with the Iroquois, they frequently heard of a mighty river lying towards the west, which the Indians called "Hohio;" naturally La Salle wished to see it. They told him that one could march many days along this beautiful river, and at last would come to the dropping-off place, the Indian's designation for the seashore. La Salle saw the possibility of this being the river that leads on westward to the "South Sea" which laves the shores of India, consequently he decided to locate the "Hohio," and determine its relations.

The three Frenchmen set out on a journey of exploration, but this trip shortly came to an end, in a way least expected.[1] In the wilderness, as they moved towards the west, they were very much surprised at meeting a Frenchman, Joliet, who for years had been wandering about the upper Mississippi basin making maps, helping the Indians, studying natural history, much of the time all alone. Joliet advised the two priests, who were accompanying La Salle, that it was their duty, instead of seeking unmapped rivers, to proceed to the Ottawa Indians who needed their ministrations. These Sulpitian monks respected Joliet's advice, and started on their way to the Ottawas.

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[1] Parkman, *La Salle and the Discovery of the Great West*, pp, 12–27. Boston, 1884.

La Salle was left alone to find the Ohio river. The record of his travels the next four years is not entirely clear; there are many statements concerning the extent of his explorations, and some of the allegations have been examined and accepted by modern historians. It is generally conceded that La Salle discovered the Ohio river, probably in 1669. It is certain that after parting with the Sulpitians he returned to the Iroquois, procured guides and proceeded again to the west, keeping south of Lake Erie, where any one of many tributaries might have directed his course to the master stream. In a later century, water communication between the Ohio river and the Mohawk lowland was established through the Erie basin, and a few years after this, by the same basin, railroads brought the upper Ohio region into industrial relationship with New York City. Geographic conditions favored La Salle's enterprise.

The Virginian expedition. Another attempt to reach Ohio was made in 1671. A party was organized by Governor Berkeley, of the great colony of Virginia. Lands extending westward across the Appalachians had been granted to this colony, and Governor Berkeley wished to know something of this unexplored region. There were frequent reports as to the country beyond the Appalachians; one common report was that on the other side a man had seen a mighty river that flowed across the horizon westward. It was suspected that this river might lead into the "South Sea." The governor accordingly organized a party, under the command of one Thomas Butts, to be guided by Indians. They set out, and journeyed about twenty-nine days; at first they passed southwest through a valley, but the last sixteen days they followed a northwest flowing river. The first part of the journey was doubtless along the Greenbrier. After traveling some days to the northwest they noted a mighty roaring and farther on found its cause, the great falls of the Kanawha. The commander was unable to get his Indians to go beyond this point; it was a frightful country down the river, they said, a place where no drinking water was to be had. So the expedition came to an end, within easy reach of the Ohio river. The route of this party is the most feasible one from central Virginia, the one selected for the Chesapeake and Ohio Railway.

CLAIMANTS OF THE AREA NOW OHIO

Its geographic relationship to other regions often decides the ownership of a particular area; and for the same reason, the "other regions" may shift from one master to another. The application of this principle is best seen in accounting for the changes in the political affiliations of a state or a nation. Several peoples have claimed to own the region of which Ohio is now a part.

CLAIM OF THE IROQUOIS CONFEDERACY

The Five Nations claimed this territory, having acquired it, they urged, through conquest. It is a fact that this combination of strong eastern tribes did drive out of the Ohio, Indiana, and Illinois areas all other Indians, making thorough conquest to the Mississippi river. Having done this, the Five Nations asserted that they owned the territory; and on the basis of this claim, at a later period, deeded it to the British, who based their ownership on this deed. In recent years, the Museum of Natural History of New York State has brought to light many facts bearing on this Indian conquest; much of the data was procured from Indian sources, and is quite as pertinent as the English discussions of the title which the Iroquois transferred. The evidence appears to show that the Five Nations, through a campaign which was the more easily made successful by causing it to be understood that they were aided by powerful white allies, either defeated or spread consternation among these western tribes. Many of the prairie Indians fled, and very few fell into the hands of the Iroquois. Gradually these dispersed tribes moved again into their own territory, and reoccupied it successfully as far eastward as the Muskingum valley. Furthermore, all later attempts of the Five Nations to dispossess them were successfully thwarted, largely because of the organization made among these Indians by La Salle, who in the meantime had returned from France with a royal license to carry on his fur trade. He, in a way, is responsible for the western Indians reoccupying the territory out of which the Iroquois Confederacy had driven them.

Such a temporary conquest, followed shortly by a reassertion of power on the part of those who had been dispossessed, hardly constitutes an equitable title; but it was satisfactory to Governor Nanfan of the New York colony, who procured the deed for the English. This whole question was reviewed very critically in 1839 by General William Henry Harrison, in whose opinion the Five Nations never established a right to land west of the Scioto river;[2] General Harrison conceded what others did not, the distance between the Muskingum and the Scioto.

CLAIM OF THE FRENCH

Basis of claim. Frenchmen, however, asserted ownership over this territory. North America, as a continent, was claimed by Great Britain on the basis of discovery made by John Cabot, who did discover an island off the eastern coast of Canada. If there was any virtue in this claim, surely the nation whose citizens first walked over much of the continent itself could well assert its title; accordingly this Ohio country belonged to the French, because her emissaries in evangelization and industry had tramped this basin back and forth for about a century before the French and Indian war. Not only had they founded trading posts, but they had organized a few colonies, whose industry, even in the manufacture of wheat flour, was felt in Europe; the first shipment of flour went southward from the Wabash country in 1746.[3] The French, entering the continent through the St. Lawrence river, spread easily across the low divides of the Great Lakes' basin into that of the Mississippi, and with scarcely less difficulty through certain adjacent parts of the Allegheny plateau.

The particular part of the basin in which we are interested was visited first by Joliet. More than this, the industries of the whole region were monopolized by the French for many decades before any competition appeared. At several points along the Great Lakes, the French maintained trading posts which were widely known among the Indians, much to their advantage.

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[2] R. King, *Ohio*, p. 40, in American Commonwealth Series.

[3] B. A. Hinsdale, *The Old Northwest*, 1889, p. 50.

Competition in fur trade. In 1664 an English ship entered New York bay, representing the Duke of York; it anchored off New Amsterdam. A force was landed, and shortly the British had conquered the Dutch, New Amsterdam becoming New York. Not long after that this English colony was governed by an Irishman named Dongan. Dongan had learned that there was great profit to be had in exchanging flashy articles with the Indians for furs. With his sanction, English traders made a trip by way of the Mohawk lowland up the Great Lakes as far as Mackinac, in the summer of 1686. Durantaye, the commandant in charge of the garrison at Mackinac, was absent. The British furnished the Chippewas with flashy goods and rum, obtaining all the furs they had. When the Frenchmen returned, they discovered the loss of a season's profit. The trip was so successful from the English traders' point of view that they decided to repeat it the following year; the governor himself became a patron of this second expedition, and sent a guard of soldiers to accompany them, under command of Major Patrick McGregor. This semi-military proceeding was a confession on the part of the governor that the method of the preceding year was not entirely commendable. The French, in the meantime, suspected that the trip might be repeated, and laid their plans accordingly. They did not even wait for the English to reach Mackinac, but met and captured each of the two flotillas into which the English party was divided. Major McGregor and his soldiers were well cared for as prisoners; the traders and their cargoes were turned over absolutely to the Indians.

The French took steps at once to see to it that a repetition of such trade exploits as this should be hazardous for the English. Other points south of Mackinac were fortified, and trading posts were more widely distributed. Cadillac, in 1701, was ordered to establish a fort where Detroit now is, and properly fortify it. These trading posts in Indiana and Ohio were subject to the fort at Detroit; such posts were established at Sandusky, along the Cuyahoga, and the Maumee, and wherever else in Ohio the Indians were in the habit of congregating.

Equity of claim. A sense of fairness will grant that, so far as discovery bears with it equity, this region, including Ohio, was rightly claimed by the French. If peaceful association with the primitive inhabitants is itself evidence of rightful ownership, it belonged to the French. If, on the other hand, the planting of colonies and bringing the area under agriculture, is necessary for ownership, only a small part of it can be said to have belonged rightfully to the French, because they looked upon this great area more as a field for trade with the Indians than as a section which they might colonize, and from which they might win agricultural returns. In only one part, away from the immediate environment of the St. Lawrence, did the French have agricultural colonies; in sections of Indiana and Illinois, the central points of which were Kaskaskia and Vincennes, they did colonize, and some agricultural returns from these communities reached Europe.

CLAIM OF GREAT BRITAIN

Royal charters. From the premature efforts of Walter Raleigh to the time of the regular plans of James Oglethorpe, the decades abound in charters issued by the British kings to loyal subjects, granting boundless lands in the New Continent, of the limits of which they were entirely ignorant. These charters were usually inexpensive; and many favors to royalty were rewarded by issuing charters to cover unknown territory in America. Slight effort was made to collate the boundaries of these land grants; frequently different individuals and companies had charter titles to the same territory. These charters are not very interesting reading today; they are buried in the customary verbiage of Anglo-Saxon law style. The grants were not accurately defined; sometimes the northern and southern limits were fixed by degrees and minutes of latitude; the westward limits, if referred to at all, were supposed to be the "South Sea," or the Pacific Ocean, but nobody knew its location in reference to the grants.

Discovery by John Cabot. But the English based their ownership of America as a whole on the right of discovery by John Cabot, a Mediterranean citizen whom the English had hired to explore for them. John Cabot had scarcely done more than to sight the mainland, but this was ample in a land so large that generations passed before interests became too conflicting. At length, with the expansion of settlements and the activity of traders, collisions between the English and French arose. Then England established other claims to territory not already in their possession. This came first through their affiliations or alliances with the Five Nations, the Iroquois Confederacy.

Deed from the Iroquois Confederacy. The very year that Cadillac made a military post at Detroit, 1701, Governor Nanfan of New York colony met the Indian chiefs where Albany now is, on the Hudson river. These Indian chiefs were themselves somewhat frightened; they had learned of the successful aggressiveness of the French in reference to the English trade. They were aware of the fortified settlement at Detroit and of the minor posts at different points of Ohio, Indiana and Illinois. They had been made ignominiously aware of the prowess of the western Indians under French organization and guidance. Consequently the Iroquois Confederacy was ready to form a mutual alliance with the British. July 19, 1701, this Confederacy deeded to Great Britain, through the governor of New York, land won by conquest, including a strip 800 miles long and about 400 miles wide, which, they said, their fathers had acquired by conquest some eighty years before. Thereafter, so far as this part of North America was concerned, the British jurists could urge better claim than Cabot's discovery. All the nations of Europe from the time of Philip of Macedon had accepted conquest as a sufficient reason for claiming ownership. Nevertheless, another governor of the New York colony, twenty-five years later, had this deed renewed by the Iroquois Confederacy.

France and Spain did not contest England's ownership of the coast colonies land. That narrow strip between the Appalachians and the sea the English were left to colonize, but both countries said that England's territory ended with the crest of the Appalachian mountains; and that the region of the streams which had their sources in the Appalachian mountains and flowed westward belonged to them. England's claim to the whole area was urged on the basis of discovery by John Cabot, and to a particular part of the Mississippi basin on the basis of deed from the Five Nations. Nevertheless, to trace the evolution of England's ownership requires reference to other transactions.

The French and Indian War. It was inevitable that France and England should clash in this country. The rivers of the Atlantic slope occupy beautiful valleys, which tempted congested population across into the valleys and plains beyond the mountains. The Atlantic coast was being overpopulated rapidly, and already many of the hardy Anglo-Saxon colonists had scaled the divide and were living in the Mississippi basin.

Only resolute people were colonists in early times; the sturdy characters of old communities became frontiersmen. Today travel is easy, and the struggle upon arrival is tempered by industrial opportunities. But in the early days it did require some courage even for the journey, and much faith for the struggle in the wilderness; usually only the fittest men and women faced these. The most courageous of the sea-board settlers found their way over the Appalachians, and they went for the purpose of making homes, but this movement into the wilderness of the west was obstructed by the French and the Indians.

The border disturbances were intermittent but chronic. Often the Indians were urged on by the French traders and *coureurs des bois*. The regular outbreaks between the Frenchmen and the British colonists in America were always side issues of open warfare in Europe. The "French and Indian War," terminated by the treaty at Paris, was the American side of the Seven Years' War. In this struggle France lost her American possessions. King George of England then became the monarch of all North America east of the Mississippi river. Heretofore the section west of the Appalachians had been "royal domain" under the French king; now by the "King's Proclamation," October 7, 1763, this became "crown" possessions of George III. Where then did the charters of the colonies come in, those generous charters, most of which mentioned lands reaching to the west as far as the "South Sea?"

George III's "royal domain," and the Quebec Act. King George in this proclamation expressed particular concern for the Indians; he desired to protect them against the encroachments of the whites, who, as we have already seen, were converting their hunting grounds into wheat and corn fields. The King forbade settlements beyond the basins of the Atlantic colony rivers; and he directed, furthermore, that all persons already beyond these limits should remove at once. Complaints arose among King George's subjects on this side of the Atlantic. Many ardent spirits of the older colonies, even before the French and Indian war, had fixed their abodes west of the Appalachians; others continued to do so. As loyal soldiers of their king, they had marched through many valleys tributary to the Ohio; they learned how desirable was this territory from which they had been almost entirely excluded by the French. But legally they were no better off after their important aid to the British victory over France; their own countrymen continued the plan of the French governors and traders.

Another effort on the part of Parliament seemed necessary to keep the colonists out of the Ohio valley. The Quebec Act of June, 1774, made the region between the Ohio and Mississippi rivers and the lakes a part of the province of Quebec; the whole area was to be governed from Quebec, and the coast colonies therefore were shut off from any legal association with it. After the treaty of 1763 officers had been sent to the various posts which the French had established. Some of these were very tactful in their association with the Indians, but others were not. Trouble continued; the presence everywhere among the western Indians, of French voyageurs and similar nondescripts from the English settlements did not tend to peace.

Difficulties with Indians in enforcing claim. After the success of the English had been assured, but before the treaty of Paris was signed, Sir William Johnson visited Detroit and other points in the recently acquired territory; his object was to conciliate the Indians, and he returned, feeling that he had won their support for the English. It was not long before the English learned that the very chiefs whom they had entertained were perpetrating a revolt; Pontiac's war soon broke out; from the standpoint of the Indians, it was a success; probably two thousand whites were slaughtered, and only two posts were left in the hands of the British, Fort Pitt and Detroit. The western Indians were still loyal to the French. It was necessary for the English to demonstrate their ability to control this region, the Indians and renegade Frenchmen. At once expeditions were sent out; one from Fort Niagara under Colonel Bradstreet, another from Fort Pitt under Colonel Bouquet. Bradstreet was to take his force up the Great Lakes as far as Mackinac, then return south to Sandusky and meet Bouquet, who in the meantime was marching westward from Fort Pitt through the central part of Ohio. Before Bradstreet had proceeded far, however, he was met by a delegation of very penitent Indian chiefs, of the Delaware and Shawnee tribes; they convinced Bradstreet of their sincerity; nevertheless, at that very time their warriors were continuing the butchery of frontiersmen. Bradstreet at once sent a message southward to intercept Bouquet, informing him that an armistice had been concluded, but Bouquet read between the lines the real situation, and continued his march into Indian territory. After reaching the Muskingum river, he established a camp near the site of Dresden. Within two days the chiefs of the above tribes, also of the Senecas, appeared on a mission of peace. Colonel Bouquet had had experience with the Indians; he read from their faces what their lips did not say. The Indians feared this man whose strategy had saved Fort Pitt the year before, and within a few days he succeeded in making these chiefs acknowledge what they had really been doing. After their conference with Colonel Bradstreet, they had improved the interim by removing some remaining whites who had escaped former pillages; it was their hope to befog this other colonel, so that they might have time for completing the carnage. But Bouquet knew how to negotiate with Indians; he drew from their own lips the testimony which convicted them. He kept the chiefs in suspense several days; at last, in a final audience he gave them to understand that they could secure peace only by delivering to him within twelve days all the prisoners they had taken from the settlements.

This demand was complied with to the satisfaction of Colonel Bouquet. The Indians delivered 206 prisoners, 81 men, the rest women and children. This outcome of the expedition was eminently satisfactory to all parties concerned. Thus the British gradually developed confidence between themselves and the Indians in this country; and this confidence was seldom abused till after the Revolutionary war, when trouble commenced again, partly through the lack of diplomacy on the part of the white men.

The trans-Appalachian area secured to the English. The claim of England to a large part of America was established by their defeat of the French. In addition to the terms of the Treaty of Paris, 1763, by which French influence theoretically terminated, the English were making progress in getting on with the Indians. Still there were many conflicting interests to be harmonized. The French settlers, by this treaty, were shifted under a new religious and legal control; the English settlers were disappointed and vexed over the disposition made of the acquired territory that backed their narrow seaboard holdings; and companies in England were always devising new plans for exploiting the colonies.

Even without the assistance of the mother country, the English colonies eventually would have gained the trans-Appalachian territory. Their compact arrangement on the seaboard, with the protecting mountain barrier on the west, conserved their energy without loss during the aggressive period of French trade expansion in the interior, and gave momentum when the colonists assumed the aggressive. The French military posts were too far from their base, France, for they had not made a business of developing colonies in America; there were no overpopulated areas in New France. No barriers had imposed intensive growth on the French settlements. Before the final struggle, the English colonists were practically in possession of the Mohawk pass, and were familiar with the breaks in the mountain barrier farther south.

CLAIM OF VIRGINIA

King George, as soon as the Treaty of 1763, terminating the French and Indian war, had been concluded, proclaimed this territory "royal domain," and asserted that the colonies had no more business in it; that it was to be held for the Indians. The British fur-trading companies were active; it was decidedly to their interests to keep Canada and the Mississippi basin one great game preserve, and the redmen as tenant trappers. The zeal with which the colonies went into the French and Indian war was partially selfish; they wanted more land. It was to be expected that the king's disposal of the lands acquired from France would cause disappointment in the colonies. This, they thought, is not gratitude; it is selfishness.

Population of Virginia. For more than a century before the Revolution, Virginia was the most populous of the colonies.[4] The need for more territory was imperative. Even before the French and Indian war, frontier settlements had been made in the Shenandoah valley. As fast as the resistance of the Indians could be overcome, the head streams of the Ohio's tributaries were dotted with cabins. When the more attractive areas near the major stream could be occupied, the wilderness of the western

[4] *A Century of Population Growth in the United States*, p. 9, Washington, 1909.

Appalachians was deserted except by the west-bound pioneer. Geographic conditions thus account for the first trans-Appalachian settlements being opposite Virginia.

Dunmore's Indian war. Dunmore, the royalist governor of Virginia, decided that he would take the initiative in punishing the Indians who continued to harass Virginian frontiersmen. Though George III had forbidden settlement in the western valleys of the Appalachians, or the fertile plains beyond, Dunmore led a force into this northwest territory, for the purpose of subduing these tribes. Dunmore organized two forces to proceed into the Indian land; one under Dunmore himself went through western Pennsylvania; the other, under General Lewis, appears to have moved directly from Virginia through the Greenbrier valley, thence down the Kanawha. The second division, in October, 1774, at the mouth of the Kanawha, met and defeated a band of about one thousand warriors commanded by the famous chief, Cornstalk. General Lewis had in his command about one thousand five hundred frontiersmen of Virginia. This battle was really the beginning of the Revolutionary war. Here, not at Lexington, the first blood was shed in resentment of George's policy. After the battle of the Great Kanawha, Lewis crossed the Ohio river and proceeded to join his commander who had constructed a fort near where Chillicothe now stands. Already the Indians had begged Governor Dunmore for peace, and a treaty was made, the Indians assenting to their conquerors' demands.

Dunmore placed the rights of subjects above the whims of kings. The colonists moved westward in spite of George III. Unfortunately the Indian onslaughts were sometimes inspired by the representatives of Great Britain, usually narrow-minded officials and traders, and occasionally the hasty acts of the settlers aggravated matters. Race evolution made it necessary to displace the Indians; it was a question of survival. Governor Dunmore doubtless felt that if he could overawe the Indians, the colonists might move on in greater numbers and so firmly occupy the area that the Quebec Act would be futile.

Campaign of George Rodgers Clark. The just rebellion of the colonies against the selfishness of the mother country was imminent in the resolutions placed before the House of Burgesses by the Virginian, Patrick Henry. During part of the Revolutionary war he was governor of his state, and in that position rendered his country valuable service.

Virginia, at the beginning of the war, had numerous citizens living in Kentucky. One of these citizens, George Rodgers Clark, petitioned Patrick Henry to be commissioned to look after the region north of the Ohio; his wish was granted. This area was inhabited by Indians who for some time had been living peacefully, and by many quiet French settlers. Clark, with a small body of volunteers, moved northward, and took possession of the various forts which were in command of English officers; he planned to proceed as far as Detroit, but was unable to muster sufficient force. Clark held what he had gained, waiting the outcome of the war. During this interval he maintained very pleasant relations with both Indians and French. Virginia exercised authority over the area, making it the county of Illinois. The inhabitants "professed themselves subjects of Virginia," and "took the oath of fidelity."[5]

If conquest warrants possession, this whole region belonged to Virginia, whose territory, therefore, was larger than the other colonies combined; it included Illinois, Indiana, Ohio, Kentucky and West Virginia.

Influence of Clark's campaign in Peace of Paris, 1783. The real significance of Clark's work appeared in the peace negotiations. If the Americans had not secured and held the scattered British posts in the Northwest territory, their representatives at Paris could not have insisted on its being included in the terms of peace. France and Spain, as well as the American states, were parties with England in these negotiations. Honesty and frankness did not characterize all diplomatic relations of that century. At this time the new Republic felt that France was her friend. Our chief representative was Benjamin Franklin, a man of such absolute honesty that he was slow to recognize the earmarks of dishonesty. France admired those who quarreled with her own enemies; largely for this reason did France, as a nation, aid the American colonies. The French minister, however, did not hesitate to open secret negotiations with the British, that he might further the interests of Spain. Already Spain owned the region west of the Mississippi and proposed in the *sub rosa* dealings to extend her possessions to include the whole Mississippi basin from the headwaters of that river eastward to the western end of

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[5] Judson Harmon, *Ohio Centennial Anniversary Celebration*, 1903, p. 63.

Lake Erie and thence across the mountains to Florida. Another of our peace commissioners, John Hay, who had been in Spain, became aware of the duplicity of the French minister, and brought the matter to the attention of Franklin, who at first was unwilling to believe it. But Hay persisted, and sent an agent to England to secure further proof, if possible. John Adams, our third commissioner, agreed with Hay. The surreptitious plans of Spain and France were of no avail. When the Treaty of Paris was signed, the new Republic owned the continent between Florida and the Great Lakes to the Mississippi. George Rodgers Clark, under his commission from the governor of Virginia, had held the territory which the three nations wanted. If he had not done this, Virginia could not have exercised nominal control of the territory during the war, and our commissioners would have had slight grounds for claiming it in the peace negotiations.

CLAIM OF THE UNITED STATES CONGRESS

At the close of the Revolutionary war the thirteen original colonies were states, and among themselves the question came up as to their western boundary. Much contention had arisen over the western country after the French and Indian war. All the colonies, however, were united against King George; and, while opposing a common foe, there was little mutual strife. Congress, therefore, had to deal with several contesting claims to lands west of the Appalachians. The English officials in Canada, and at a few posts south of the Great Lakes, expected a quarrel among the young states. England, for many years after the Peace of Paris, 1783, continued to hope for a recurrence of strife, the outcome of which would be different. According to the custom in Europe, a treaty merely meant an opportunity for the contending factions to strengthen themselves and then renew the fight. England anticipated factional disputes in this young family of states; then England's emissaries would arrange an alliance with one faction, hoping to again get possession of these lost colonies.

State claims conceded to the federal government. Of the several states that had claims west of the Appalachians, Virginia apparently had the best. A quite definite charter and a very distinct conquest of the area during the Revolutionary war enabled Virginia's lawyers to make out a good case. On the other hand, New York State felt that it also had an exceedingly good title to part of the territory west of Pennsylvania, a title which was satisfactory to the English jurists: the deed given by the Iroquois confederacy to the English governor of the colony which had now become the state of New York.

Congress could do little if the commonwealths were to become embittered over such dissensions. This was the time for magnanimity. New York State was the first to relinquish to Congress her title to the disputed territory. Not to be outdone in acts of patriotism, Virginia, through Governor Thomas Jefferson, deeded to Congress her possessions north of the Ohio river. If the two states which had the best claim on this territory yielded their title to Congress, it were indeed petty for the other states to offer further obstruction. The English were again disappointed; the dissensions gave way to higher motives.

The Northwest Territory. The necessity for the United States Congress coming immediately into legal possession of that territory was financial. The Revolutionary war closed with the defeated army of a resourceful nation on one side, and the victorious army of a bankrupt people on the other. The Continental Congress had borrowed of all of its loyal citizens at home and British haters abroad. At once Congress arranged to dispose of this western property, that the new Republic might raise the funds to meet imperative obligations.

The creation of the Northwest Territory and the beginning of regular settlements in Ohio were about coincident. Congress made General St. Clair governor of the western lands, and issued a proclamation, warning all disorderly persons out of the area. Congress, about the same time, also provided for a survey of the region, that the land might be definitely laid out and turned over to prospective purchasers.

SUMMARY

Some of the geographic features of North America as a continent have been noted in the early history of the Ohio country. The prehistoric inhabitants of the area probably came from the west, having spread across the central Mississippi basin. North of the Ohio river there were frequent changes in Indian supremacy, because it was impossible to successfully guard the region against invasion, except on the east; even on that side the French were not able to hold Ft. DuQuesne against the British. The St. Lawrence and the Mississippi rivers aided European explorers in penetrating the continent; citizens of France were the first to investigate the St. Lawrence, and their activity centered in its basin till the whole region was won by England.

Any people inhabiting the northern colonies eventually would be enticed westward through the Mohawk gap, thence along Lakes Ontario and Erie into the Ohio country. The Appalachian barrier checked the youthful energy of the early English explorers and nurtured the coast settlements into the nucleus of a strong nation. The more difficult passes, and broader wilderness belt south of New York did not permanently restrain the hardy frontiersmen.

Because of its geographic environment, the land between Lake Erie and the Ohio river has supported a succession of inhabitants, and been subject to several rulers:

1. The Ohio area was first occupied by people of whom we know nothing; books simply speak of them as "prehistoric." Ownership must have been well established by this unknown people; there is scarcely a county of the state in which their works are not found, representing great labor. Whoever these early inhabitants were, they worked. Whatever may have been their purpose, this labor represents some motive that must have actuated them as a people. The great earth structures that abound, adjacent to, and in many of the wide fertile valleys of Ohio, less frequently on the intervening hills, represent more than individual ambition. This must have been an ambitious people; their mute testimonials will long endure. The location of their more extensive works reflects the influence of topography; later inhabitants have very often selected the same sites. Possibly these prehistoric settlers had to contest the ground with earlier inhabitants, or to repel invasion.

2. After these came the American Indians, who were scattered about the state when the first white man visited the area. Their ownership was based on "squatter sovereignty" which, under some restrictions, has usually been a sufficient title among English peoples. The Indians of Ohio never occupied the territory long in peace; they were frequently harassed by the strong Iro-

quois Confederacy. Furthermore, they were hemmed in on the south by the Cherokees, who were often aggressive. So Ohio was never held continuously nor controlled by a particular tribe of Indians. Its physiographic environment invited conquest. The Ohio river was no barrier, but rather a route of approach for southern tribes; and Lake Erie made the area very accessible for the predatory bands of New York. Without the restraints of civilization, the Ohio country would never have become prosperous; but under stable conditions, the geographic features that formerly invited chaos have become a very important asset.

3. Next the French felt that they had acquired title to this region. Spurred by the trade efforts of Governor Dongan of the New York colony, the French pushed their permanent forts farther south, and then established trading posts through Ohio. They possessed the territory, therefore, so far as trade relations were concerned. In addition, they usually showed some spiritual concern for the Indians and ministered to them in this state, as elsewhere. The first whites to discover Ohio were the French.

4. The English kings issued charters to their subjects, disposing of territory which embraced Ohio and all the country west. These paper concessions were at variance with the fact of French possession, but for a long time geographic conditions averted collision. Slowly the interests of the two peoples came into conflict; the relief features of the French territory had imposed no barriers, but did encourage a scattering of energy; in the struggle, the French were the weaker.

5. By the Treaty of Paris, 1763, England became the legal owner of the trans-Appalachian country; this treaty was acknowledged by all Europe. Therefore, from the standpoint of European methods, England won the first title.

6. For some time before, and more numerously after, this transfer to the English, frontiersmen from the colonies came into the territory, and took possession without legal process. Such a procedure was one of their purposes in their final struggle with France. Many of the colonies maintained that some of the area across the mountains was theirs by charter grants. King George did not sanction this settlement of the West; his Quebec Act was one of the many causes that led to the Revolution. The colonies, winning in this war, and becoming states, again announced their claims.

7. Shortly after the close of the Revolution, this region, including the concessions of the individual states, became the property of the United States Congress, and was organized as a territory. In 1803, a portion of this Northwest Territory became the state of Ohio.

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